Long-Term Ecosystem Monitoring Program at Cape Cod National Seashore

2002 Update of the Conceptual Framework for the Development of Long-Term Monitoring Protocols at Cape Cod National Seashore

Prepared by:

Kelly Boland, Wildlife BioTech
Robert Cook, Wildlife Ecologist
Evan Gwilliam, Aquatic Ecologist
Carrie Phillips, Inventory & Monitoring Coordinator
John Portnoy, Ecologist
Stephen Smith, Plant Ecologist

Cape Cod National Seashore
99 Marconi Site Road
Wellfleet, Massachusetts 02667
508-487-3262

Table of Contents

Introduction

Cape Cod National Seashore's (CACO) Long-Term Ecosystem Monitoring (LTEM) Program was established to serve as a prototype for monitoring the ecosystems of parks along the Atlantic and Gulf coasts. Our responsibilities include:

- developing an ecological monitoring program that is scientifically sound and relevant to management of park resources;
- testing inventory and monitoring methods;
- developing and implementing long-term monitoring protocols;
- conducting studies to help refine monitoring questions and to interpret monitoring results; and
- sharing our experience and technical expertise with other parks and Monitoring Networks along the Atlantic and Gulf coasts.

The Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore[1] is the foundation of the Cape Cod LTEM Program and describes the ecosystem-based, issue-oriented approach that has guided program development. Part I of the Framework describes the conceptual models used to represent predicted relationships among agents of change, stresses, and ecosystem responses. These models, developed and interpreted by panels of subject matter experts, provide an objective basis for selecting specific monitoring components. Part II of the Framework summarizes the monitoring protocols proposed as the initial core of the Cape Cod LTEM Program.

The authors of the Framework called for the Cape Cod LTEM Program to be flexible and dynamic ". . . inviting the development of new protocols: as issues emerge, as the interpretation of monitoring data identifies agents or responses that are now unknown, as predictive modeling efforts require additional information, or as new monitoring techniques are developed." The ecosystem-based, issue-oriented approach and conceptual ecosystem models described in Part I remain valid and continue to provide fundamental guidance for our program. Thus far, the program has evolved with respect to the scope, focus, and status of protocol development efforts. The purpose of this document is to describe that evolution by updating Part II of the Framework.

Given that Part I of the Framework remains current, and that Part II of the Framework provides essential history and context for the program, it is important that this update be viewed as an addendum to the 1999 Framework and not as an independent document.

[1] Roman, C.T. and N.E. Barrett. 1999. Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore. USGS Patuxent Wildlife Research Center, University of Rhode Island. 59 pp.
http://www.nature.nps.gov/im/monitor/caco.pdf

Summaries of Monitoring Protocols

The 1999 Conceptual Framework identified 19 initial protocols and provided summaries for 15 of those listed. As of October, 2002, we are developing, or plan to develop, 33 monitoring protocols and related inventory projects. This change reflects refinement of comprehensive protocols into smaller and more focused monitoring projects, the addition of new monitoring components, and the deletion of one of the originally proposed protocols.

The growth from 19 protocols to 33 is largely the result of separating components of single protocols called for in 1999 into individual monitoring efforts. The original monitoring components that have been divided into separate protocols are vegetation, waterbirds, and landbirds. We have expanded the scope of the proposed vegetation monitoring efforts to specifically include plant communities of particular management concern: salt marshes, dune slack wetlands, kettle pond margins, woodland vernal wetlands, Province Lands ponds, dune grasslands, heathlands, and coastal forests. Each of these plant communities requires a unique monitoring approach in order to capture the types of ecosystem responses associated with the agents of change and stresses affecting each habitat type. As work progressed to develop the waterbird monitoring component, we recognized the importance of capturing four distinct groups of waterbirds: migrating shorebirds, colonial-nesting waterbirds, marsh-breeding birds, and piping plovers. As with the vegetation communities, each of these waterbird groups requires a unique monitoring approach, and each is closely identified with a different ecosystem type. Two distinct approaches have emerged for satisfying our landbird monitoring objectives: avian point counts, which follow changes in distribution and abundance across the park; and the Institute for Bird Populations' MAPS program (Monitoring Avian Productivity and Survivorship) which provides information on the relationships among the influences of residential development, vegetation communities, and avian productivity and survival.

Four monitoring components have been added to the program: estuarine benthic macrofauna, beach macroinvertebrates, reptiles, and small mammals. We are also planning to conduct an inventory of the park's lichens. As described in the protocol summaries that follow, each was developed in consideration of the conceptual ecosystem models in Part I of the framework.

Lastly, we have dropped development of a white-tailed deer monitoring protocol. White-tailed deer were originally proposed for monitoring because of their high management importance in many other eastern parks. Parks that are within suburban landscapes often have very dense white-tailed deer populations due to the absence of predators and prohibitions on hunting. The intense herbivory can change the structure of plant communities within the park, and the density of deer can present a safety hazard to motorists. Due to CACO's size and rural setting, and since hunting is permitted within the park, we have not experienced the kinds of deer population dynamics or management conflicts seen at many other parks. Also, after considering these differences, we concluded that protocol development work based on Cape Cod would be of limited utility to suburban eastern parks where deer are a priority issue. Information collected by the

Commonwealth of Massachusetts, which manages deer hunting on the Cape, and through our vegetation and meso-mammal monitoring protocols should alert us to population or plant community changes that would warrant re-consideration of white-tailed deer monitoring.

The protocol summaries that follow reflect these changes as well as developments in the scope, focus, and status of the originally proposed monitoring components. The summaries are organized by ecosystem type. Each summary identifies the principal investigators, explains why we are developing the monitoring protocol, lists the specific monitoring questions that will be addressed, and updates the status of the project. We are also including a summary of our proposed Inter-Disciplinary Study Area approach for fostering integration of monitoring protocols across disciplines and, where applicable, across ecosystems.

We expect the scope of the program to continue to evolve over the next three to five years as protocols transition from development to field testing and analysis. We may find that the objectives of some protocols are not achievable and that specific monitoring questions need to be narrowed accordingly; or we may determine that long-term implementation of some protocols is infeasible given available resources. Conversely, new information may direct us to consider new monitoring components. We expect that the next few years of refining the program's scope will resolve with a core of long-term monitoring protocols and a dynamic suite of discrete related studies.

ESTUARINE NUTRIENT ENRICHMENT

PRINCIPAL INVESTIGATOR/COOPERATORS:

Charles Roman, National Park Service; Barbara Nowicki, University of Rhode Island; funding from USGS-BRD

JUSTIFICATION:

Increasing residential development adjacent to CACO creates the potential for excess nitrogen loading and eutrophication of estuarine systems. Eutrophication increases or changes the dominant primary producers, possibly leading to declines in dissolved oxygen, alteration of benthic invertebrate and fish communities, and other habitat changes. Shallow embayments appear to be particularly at risk; studies throughout much of the world (Valiela et al. 1992, Kinney and Roman 1998, Lavery et al. 1991, Sfriso et al. 1987) have shown a macroalga-dominated response to nutrient enrichment in shallow coastal systems. In nearby Waquoit Bay (Falmouth, Massachusetts) nitrogen loading from residential development and on-site wastewater disposal has led to green macroalgae blooms and subsequent loss of eelgrass habitat (Valiela et al 1992, Short and Burdick 1996). These dense macroalgae mats can create anoxic conditions at times of water column stratification (D'Avanzo and Kramer 1994).

Increasing residential development around CACO boundaries creates the potential for excess nitrogen loading of local coastal embayments. As primary production in saline coastal waters is primarily nitrogen-limited (Howarth et al. 1988), these anthropogenic nirtogen inputs may increase primary production, leading to eutrophication within and adjacent to CACO's shallow estuaries. CACO lacks comprehensive information on how estuarine water quality may be changing in response to nitrogen loading and on how primary producers and consumers are responding.

Information from the meteorologic and atmospheric monitoring and ground-water quality monitoring protocols will be integral to interpretation of the results of the estuarine nutrient enrichment protocol. Regarding estuarine consumers, this protocol is directly linked to the nekton monitoring component of CACO's I & M program.

MONITORING QUESTIONS:

1. Is nitrogen loading from terrestrial and atmospheric sources changing?
2. What is the response of the ecosystem to changing nitrogen loading, with the focus on primary producers?
3. What are the thresholds of nutrient loading?

STATUS: In Development

A proposal for protocol development was prepared in 1998 (Roman and Nowicki 1998) and field work began in 1999.

CITATIONS:

D'Avanzo, C. and J.N. Kramer. 1994. Diel oxygen dynamics and anoxic events in an eutrophic estuary of Waquoit Bay, Massachusetts. Estuaries 17:131-139.

Valiela, I. et al. 1992. Couplings of watersheds and coastal waters: sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts. Estuaries 15:443-457.

Kinney, E.H. and C.T. Roman. 1998. The response of primary producers to nutrient enrichment in a shallow estuary. Marine Ecology Progress Series 163:89-98.

Lavery, P.S., R.J. Lukatelich and A.J. McComb. 1991. Changes in the biomass and species composition of macroalgae in a eutrophic estuary. Estuarine, Coastal and Shelf Science 33:1-22.

Roman, C. T., and B. L. Nowicki. 1998. Design and Testing of a Sampling Protocol for Monitoring Estuarine Water Quality. CACO Files. 22 pp.

Sfriso, A., A. Marcomini and B. Pavoni. 1987. Relationships between macroalgal biomass and nutrient concentrations in a hypertrophic area of the Venice Lagoon. Marine Environmental Research 22:287-312.

Short, F.T. and D.M. Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. Estuaries 19:730-739.

SALT MARSH ELEVATION CHANGE IN RESPONSE TO SEA-LEVEL RISE

PRINCIPAL INVESTIGATOR/COOPERATORS:
Michael Erwin and Don Cahoon, USGS Patuxent Wildlife Research Center; Charles Roman, NPS-CESU; funding from USGS-BRD

JUSTIFICATION:
The mean elevation of salt marsh surfaces must increase to keep pace with the annual rise in sea level and subsidence of salt marsh organic substrates. If the sedimentation rates in a salt marsh do not equal or exceed the net loss in elevation due to the steady increase in sea level and salt marsh subsidence, it will "drown". When a salt marsh "drowns", the surface of the marsh becomes sub-tidal which can cause drastic habitat changes such as the conversion of vegetated salt marsh to unvegetated mud flat.

As recognized in the 1999 Conceptual Framework, understanding changes in relative salt marsh elevation is important for interpreting changes in salt marsh vegetation communities and other estuarine ecosystem components. Salt marsh erosion and accretion is also an important parameter for measuring the response of formerly impounded marshes to restoration of tidal influence, and will be particularly critical if the rate of sea level rise accelerates as predicted.

In addition to monitoring sediment elevation changes in CACO's salt marshes, this project is also part of a worldwide effort to monitor sea level rise with sediment erosion tables (SETs) (Boumans and Day Jr. 1993) and cryogenic coring devices (Cahoon et al. 1996). These two techniques measure the amount of erosion and accretion on salt marsh surfaces. The data collected by this protocol will be helpful for interpreting changes in salt marsh vegetation and, over the long-term, possibly benthos, nekton, and migrating waterbirds.

MONITORING QUESTIONS:
1. Is the rate of sedimentation in CACO salt marshes adequate to prevent these marshes from drowning?
2. What is the response of marsh surface elevation to tidal restoration projects?
3. Can the rate of erosion be correlated to changes in other biologic systems?

STATUS: Protocol - In Development; Monitoring - Operational
SET and cryocore monitoring sites have been established in three CACO salt marshes (Nauset Marsh, Herring River and Hatches Harbor) and adjoining impounded brackish and fresh systems. These sites have been monitored since 1998. The data are being used to monitor responses to tidal restoration and to provide baseline data for proposed marsh restoration projects. These sites are also providing data used to find correlations between

sea level rise and marsh bird populations. The monitoring methods used will be formally documented in a written protocol during 2003.

CITATIONS:

Boumans, R.M.J. and J.W. Day Jr. 1993. High Precision Measurements of Sediment Elevation in Shallow Coastal Areas Using a Sediment-Erosion Table. *Estuaries* 16 v2: 375-380.

Cahoon, D.R., Lynch, J.C. and R.M. Knaus. 1993. Improved Cryogenic Coring Device for Sampling Wetland Soils. *Journal of Sedimentary Research* 66 no.5:1025-1027.

SALT MARSH VEGETATION

PRINCIPAL INVESTIGATOR/COOPERATORS:
Charles Roman, NPS-CESU; Stephen Smith and John Portnoy, NPS-CACO; funding from USGS-BRD and NPS-CACO I&M

JUSTIFICATION:
While providing refuge for numerous plants, fishes, reptiles, migratory shorebirds and waterbirds, salt marshes play an important role in reducing erosion, filtering nutrient inputs, and shoreline protection (Bertness 1999). Although there are relatively pristine salt marsh areas within CACO, others have been severely degraded by human-related activities. Restrictions to tidal flow, for example, have had major impacts on salt marsh habitat. This has lead to several restoration initiatives, including Hatches Harbor and East Harbor where tidal restrictions are currently being remedied. However, eutrophication, sea-level rise, acid deposition, and recreational use also pose significant threats (Portnoy et al. 1998, Roman et al. 1999). The development of a long-term salt marsh vegetation monitoring program will allow scientists and managers to evaluate the success or failure of restoration efforts and assess both natural and human-related influences on salt marsh habitat throughout CACO.

This protocol is tied to the relative sediment elevation and estuarine nutrient enrichment monitoring efforts, and will aid interpretation of data collected by the benthos, nekton, and migrating waterbird protocols. Because salt marshes are transition zones between uplands and open water marine systems, this protocol also has links to the coastal forest and dune grassland protocols.

MONITORING QUESTIONS:
1. What is the response of salt marsh vegetation to hydrologic restoration?
2. How does salt marsh structure, function, and landscape pattern vary among the impacted and non-impacted salt marshes within CACO?
3. What physical, chemical, and biological factors are contributing to observed vegetation changes?
4. Are observed changes the result of human activities or natural processes?

STATUS: Protocol - Completed; Monitoring - Field Testing
A methodology for vegetation monitoring has already been used effectively in documenting the restoration of Hatches Harbor (Roman et al. 2001). Several new parameters are being incorporated into the protocol in an attempt to include process-related and intra-specific indicators of change, both of which may precede shifts in species composition. Plant tissue nutrients (Bradley and Morris 1992), non-structural carbohydrates (Andres et al. 1994), and morphological attributes such as plant height (Lissner and Schierup 1996, Chambers 1997, Hanganu et al. 1999) show promise as

useful indicators of plant vigor. Given that the current network of salt marsh monitoring sites exists for the purpose of tracking the progress of restoration in two areas, additional sites will be placed in the West End Marsh, The Gut, Nauset Marsh, and the Herring River. In this way, information can be acquired over a broader distribution of this resource.

CITATIONS:

Andres, G., T. McLendon, and D. Lynn Drawe. 1994. Herbage yield, protein content, and carbohydrate reserves in gulf cordgrass (*Spartina spartinae*). Journal of Range Management. 47:16-21.

Bertness, M.D. 1999. The Ecology of Atlantic Shorelines. Sinauer Associates Inc., Sunderland, MA.

Bradley, P.M. and J.T. Morris. 1992. Effect of salinity on the critical nitrogen concentration of *Spartina alterniflora* Loisel. Aquatic Botany 43(2):149-161.

Chambers, R.M. 1997. Porewater chemistry associated with *Phragmites* and *Spartina* in a Connecticul tidal marsh. Wetlands 17(3):360-367,

Hanganu, J. G.Mihail, and H.Coops. 1999. Responses of ecotypes of *Phragmites australis* to increased seawater influence: A field study in the Danube Delta, Romania. Aquatic Botany 64(3-4):351-358.

Lissner, J. and H.H. Schierup. 1996. Effects of salinity on the growth of *Phragmites autralis*. Aquatic Botany 55(4):247-260.

Portnoy, J.W., B.L. Nowicki, C.T. Roman, and D.W. Urish. 1998. The discharge of nitrate-contaminated groundwater from developed shoreline to marsh-fringed estuary. *Water Resources Research* 34: 3095-3104.

Roman, C.T., and N.E. Barrett. 1999. Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore. Technical Report, USGS Patuxent Wildlife Research Center, Coastal Research Field Station, Narragansett, RI. 59p.

Roman, C.T., M-J. James-Pirri, J.F. Heltshe. 2001. Monitoring salt marsh vegetation: a protocol for the long-term coastal ecosystem monitoring program at Cape Cod National Seashore.   U.S. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA

ESTUARINE BENTHIC MACROFAUNA

PRINCIPAL INVESTIGATORS/COOPERATORS:

Sheldon Pratt and Candace Oviatt, Graduate School of Oceanography, University of Rhode Island; funding from USGS-BRD and NPS-CACO I&M

JUSTIFICATION:

Estuarine benthic habitats and their associated communities are influenced by a variety of physical and biological factors including tidal regime, substrate dynamics, and the distribution and density of salt marsh grasses, eelgrass, and macroalgal beds. Benthic macrofauna can also be an important influence on estuarine habitats and communities through bioturbation, by providing physical habitat elements (eg. shellfish beds), as a collection of diverse consumer guilds, and as food sources for higher trophic levels.

Benthic habitats and species assemblages are also vulnerable to a variety of anthropogenic stresses. At CACO, alteration of tidal regime, eutrophication, and habitat alteration (associated with invasive species and aquaculture) are stresses of particular management concern. Not surprisingly, the 1999 Conceptual Framework identified linkages between benthic community change and a variety of agents of change and stresses affecting CACO's estuarine systems.

Detecting and understanding changes in benthic macrofauna community structure will be important to interpreting the results of other estuarine monitoring efforts and studies. We expect that the sampling which will occur during the protocol development process will be tightly linked to a contemporaneous inter-tidal mapping project and will comprise a more complete inventory of the composition and distribution of benthic macrofaunal communities. Comparing the results of estuarine nutrient enrichment monitoring with patterns of change detected in benthic macrofaunal assemblages will help test assumptions regarding the stress nutrient loading places on estuarine systems. And over the long term, understanding changes in benthic macrofauna may help us interpret any trends detected through the estuarine nekton and migratory shorebird monitoring programs.

MONITORING QUESTIONS:

Currently, we have articulated only broad monitoring questions. These questions are:

- Can we detect long-term changes in species composition, distribution, and abundance?
- Can we relate any changes detected to stresses of management concern, particularly nutrient loading, altered tidal circulation, and habitat alteration?
- And specifically, how do benthic macrofauna assemblages in systems where tidal influence is being restored (Hatches Harbor, East Harbor) compare to those in

systems with unaltered tidal hydrology, and do the similarities and dissimilarities change over time?

More specific questions will be developed during the first part of 2003. (Please see STATUS below).

STATUS: In Development
The principal investigators were identified and funds obligated for this project near the close of FY 2002. Initial tasks include literature review, refining the monitoring questions, prioritizing sites, and finalizing the project work plan (Pratt and Oviatt 2002).

CITATIONS:
Pratt, SD and CA Oviatt. 2002. Graduate School of Oceanography, University of Rhode Island. Inventory and Monitoring at the Cape Cod National Seashore: Benthic Macrofauna, Proposal to USGS/National Park Service. CACO Files. 9pp.

ESTUARINE NEKTON

PRINCIPAL INVESTIGATOR/COOPERATORS:
Kenneth Raposa, Narragansett Bay National Estuarine Research Reserve; Charles Roman, NPS-CESU; funding from USGS-BRD

JUSTIFICATION:
Threats to estuarine ecosystems include eutrophication, watershed development, wetland loss, overfishing, and other natural and human-induced problems. Long-term monitoring of estuarine natural resources is needed to document the effects of naturally occurring and anthropogenic impacts and to provide baseline datasets from unimpacted areas (Raposa and Roman, 2001).

Nekton, defined here as an assemblage of free-swimming fishes and decapod crustaceans, is an abundant estuarine fauna with unique responses to environmental change that make them desirable for inclusion in a coastal monitoring program.

The 1999 Conceptual Framework identifies estuaries as a vitally important habitat. Estuaries are the “nursery” for two thirds of commercially important fish species, habitat for popular commercial and recreational species, and habitat for species of trophic importance. These shallow estuarine habitats are constantly changing in response to storms, geomorphic processes, and habitat loss from development and tidal restrictions (Roman and Barrett, 1999).

The response of nekton populations and species composition to long-term/large-scale environmental change and restoration projects incorporates and reflects multiple ecosystem processes, and therefore indicates overall ecosystem integrity. Long-term changes in nekton assemblages will be compared to patterns of change detected through the relative sediment elevation, estuarine nutrient enrichment, salt marsh vegetation, and benthos monitoring projects.

MONITORING QUESTIONS:
1. How do nekton communities in impacted salt marshes differ from reference marshes?
2. What are responses of nekton to restoration of impacted salt marshes?
3. What is the time frame for nekton communities in restoring salt marshes to achieve functional equivalency when compared to reference marshes?
4. How are changes in nekton related to changes in other ecosystem components such as vegetation, benthos, birds, and water quality during salt marsh restoration?
5. Can the response of nekton to restoration practices be predicted prior to implementation of restoration management?
6. How do nekton respond to long-term human-induced or natural changes in the structure and distribution of estuarine habitats?

7. How do nekton respond to regional or large-scale processes such as global climate fluctuations, sea level rise, ocean temperature changes, or watershed development?
8. To what degree do nekton attributes vary inter-annually and how can natural variability be isolated from human-induced variability?
9. Are invasive species present in the nekton community, are new invasive species being introduced, are they changing in abundance, and are they affecting the structure and function of the estuarine nekton community?

STATUS: Protocol - Completed; Monitoring - Field Testing

The protocol for monitoring nekton in shallow estuarine habitats was completed in December 2001. In the spring of 2003, the nekton-monitoring program will be implemented. The monitoring effort will continue collecting data from sites in Hatches Harbor, Herring River and Nauset Marsh that were established during protocol development. Hatches Harbor and the Herring River are subjects of wetland restoration projects, and Nauset Marsh is one of the few large estuaries in the northeast that has not undergone significant impoundment or ditching. In addition to these sites, East Harbor, another possible wetland restoration site located in Provincetown and Truro, will be included. If staff resources allow, the West End Marsh in Provincetown and the Great Island Marsh in Wellfleet will be included in the monitoring effort to correspond with marsh-bird monitoring, salt marsh vegetation monitoring and estuarine nutrient monitoring efforts.

CITATIONS:

Raposa, K. B. and C. T. Roman. 2001. Monitoring Nekton in Shallow Estuarine Habitats. Technical Report, USGS Patuxent Wildlife Research Center, Coastal Research Field Station, Narragansett, RI. 39p.

Roman, C.T., and N.E. Barrett. 1999. Conceptual framework for the development of Long-term monitoring protocols at Cape Cod National Seashore. Technical Report, USGS Patuxent Wildlife Research Center, Coastal Research Field Station, Narragansett, RI. 59p.

WATERBIRDS - MIGRATING WATERBIRDS

PRINCIPAL INVESTIGATORS/COOPERATORS:

Michael Erwin, USGS Pautaxent Wildlife Research Center; funding from USGS-BRD

JUSTIFICATION:

CACO's extensive estuarine wetlands provide important foraging and roosting habitat for a wide assemblage of water birds. These include many species of shorebirds (sandpipers (Scolopacidae) and plovers (Charadriidae), gulls (Laridae), terns (Sternidae), herons (Ardeidae), and waterfowl (Anseriformes). Included among these are many species suspected of being in decline or otherwise listed as species of conservation concern by federal or state agencies. For many migratory water birds, time spent foraging and roosting in estuarine habitats is important for acquiring and conserving the energy resources necessary to successfully complete migration. Changes in any of the many parameters that affect the quantity and type of food resources, the ability of birds to acquire these resources, or the ability of birds to rest in between feedings can affect the numbers and species composition of birds utilizing habitats at CACO and elsewhere.

At CACO, water bird use of estuarine habitats is affected by depth and frequency of flooding, substrate composition, amount and type of prey items available, heterogeneity of the plant community, competition among bird species, and human use and activity. Agents of change such as development and diking create stresses on estuarine habitats through nutrient loading, pesticides, and altered hydrology that can affect water bird use directly, as well as indirectly through impacts on vegetation and invertebrate prey. In addition, human uses, such as clamming, aquaculture, visitors, and unleashed pets can disturb foraging and roosting birds causing them to lose or waste energy and potentially displacing them to sites with fewer food resources.

To better understand trends in the numbers and species composition of migratory waterbirds, monitoring will be integrated into broader monitoring of physical-chemical, geomorphic, hydrologic, vegetative, and human activity parameters of estuarine systems.

MONITORING QUESTIONS:

1. Are there identifiable “hotspots” that are used consistently by either feeding or roosting congregations of shorebird and/or waterfowl species at the scale of the embayment?
2. Are these hotspots (if found) consistent among years?
3. At the small (local) scale, are there certain habitat types that are particularly important for American black ducks (*Anas rubripes*), red knots (*Calidris canutus)*, dunlin (*Calidris alpina*) or other shorebirds of concern?
4. Is there any change in species abundance or composition occurring over decadal time periods in CACO?

5. Are methods adequate to allow meaningful comparisons of CACO population trends at selected sites with those occurring within the Cape region for shorebirds (International Shorebird Survey data).

STATUS: Protocol - In Development; Monitoring - To Be Initiated in 2003
Field testing of protocols was conducted in 1999 and 2000 (Hadden 2001). Results indicated that monitoring foraging birds around low tide produced most useful data. A protocol (Erwin et al. 2002) has been drafted and is undergoing review and revision. The recommended protocol for CACO will call for weekly counts of foraging birds at Nauset Marsh, Wood End, Great Island/Jeremy Point, and Pleasant Bay, from mid-July through October. Migrant waterbird monitoring will be conducted every three to five years. The first season of implementation is planned for 2003.

CITATIONS:
Erwin, M., C.J. Conway, S.H. Hadden, J.S. Hatfield, and S.M. Melvin (DRAFT) . Waterbird monitoring protocol for Cape Cod National Seashore and other coastal parks, refuges, and protected areas. USGS, Patuxent Wildlife Research Center. DRAFT 2002

Hadden, S. W. 2001. Waterbird Inventory and Monitoring: Report on protocol implementation and development at Cape Cod National Seashore. Cape Cod National Seashore, Wellfleet, MA 66 pp.

GEOMORPHIC SHORELINE CHANGE

PRINCIPAL INVESTIGATOR/COOPERATORS:
Mark Duffy, Assateague Island National Seashore/Northeast Coastal and Barrier (NC&B) Network; funding from USGS-BRD and NPS-NC&B Network
This work was initiated by the late James Allen, a noted coastal geologist with USGS, who passed away during the summer of 2002.

JUSTIFICATION:
The Atlantic-side or outer beach is highly dynamic over multiple spatial and temporal scales. Shorelines are changed by winds, waves, currents, tides, and sea level rise. In areas where sand erosion outpaces accretion, this change manifests in a landward migration of the shoreline. In the reverse situation, net accretion can be seen in the building of spits, beaches, and dunes. Patterns of sand erosion and deposition over short time scales define the stability of beach habitats; larger and longer scale processes, such as inlet migration and bluff retreat, can change the hydrology of estuaries and remove coastal bluff habitats. Shoreline change is also an important factor in other types of management concerns such as protection of cultural resources on or near retreating bluffs, facilities siting and management, and assessing the potential effects of shoreline hardening projects.

The information collected by this protocol will be an important compliment to beach macroinvertebrate monitoring and the protocols related to estuarine systems, particularly estuarine nutrient enrichment and marsh sediment elevation. Coastal forest, dune slack, and dune grassland monitoring will also benefit from the expansion of the LIDAR surveys (see STATUS below) to the Province Lands.

MONITORING QUESTIONS:
1. How has the shoreline changed over the last century?
2. What are the temporal scales, spatial scales, and rates of change of various shoreline position features (mean high water line, bluff tops, salt marsh margins)?
3. Where are directions of shoreline change (i.e. erosion or accretion) persistent, where are they cyclic and near equilibrium, and where are park resources at risk?

STATUS: In Development
In 1997 a proposal was prepared for development of a shoreline change monitoring protocol (Allen et.al. 1997). The project included relocating and surveying shoreline profile transects initially established in 1889, mapping the mean high water line using GPS, using remote video monitoring to study the dynamics of nearshore bathymetry and wave break positions, and using light distance and ranging (LIDAR) technology to collect detailed mapping data of the entire outer beach shoreline and the Province Lands area of the park. A draft protocol for CACO was submitted and peer reviewed in the

spring of 2002 (Allen et al. 2002). In 2001, the NC&B Network began working with Dr. Allen and his co-investigators to expand shoreline change monitoring to the other parks in the Network. In the wake of Dr. Allen's death, the Network stepped forward to continue development of a long-term shoreline monitoring protocol.

CITATIONS:

Allen, J. R., P. August, C. LaBash, and J.W. Haines. 1997. Proposal: Shoreline Change. CACO files. 21pp.

Allan, J.R., C.T. LaBash, and P.V. August. 2002. Monitoring Shoreline Change: A Protocol for the Long-term Ecosystem Monitoring Program at Cape Cod National Seashore. USGS Patuxent Wildlife Research Center. Draft.

BEACH MACROINVERTEBRATES

PRINCIPAL INVESTIGATORS/COOPERATORS:
Howard Ginsberg, USGS Patuxent Wildlife Research Center, and Jaqueline Steinback, Research Assistant, University of Rhode Island; funding from NPS-NRPP

JUSTIFICATION:
Beach stability, the abundance of wrack, and spatial relationships between foredune vegetation and wrack lines are known or suspected to be dominant factors influencing beach macroinvertebrate communities (Ginsberg and Kluft 1998). As a result, this community may be an indicator of ecosystem change that links marine processes (wave energy, erosion and deposition, inlet migration, ocean productivity as reflected by wrack abundance) with terrestrial processes (foredune dynamics, dune vegetation).

The 1999 Conceptual Framework identified several agents of change and stresses that could trigger detectable responses in the beach macroinvertebrate community. These include erosion control measures, beach renourishment, recreation, and oil spills. At CACO, three important management concerns have heightened our interest in the beach macroinvertebrate community:

- beach macroinvertebrates are the primary food source for the threatened piping plover (*Charadrius melodus*);
- a preliminary study conducted in 1997 indicated that the beach macroinvertebrate community may be sensitive to off-road vehicle traffic (Bossung 1997 as cited in Ginsberg and Kluft 1998); and
- understanding the composition and dynamics of the beach macroinvertebrate community could be critical to response and damage assessment efforts in the unfortunate event of an oil spill or other toxic release.

We expect information gained from the developing geomorphic shoreline change monitoring program will be an important complement to beach macroinvertebrate monitoring, particularly as both relate to shoreline stability. Repeated vegetation mapping at ten-year intervals may also help us test assumptions regarding the influence of foredune vegetation on the macroinvertebrate community and interpret any long-term changes detected. Spatial and quantitative changes in the beach macroinvertebrate community may also help us interpret changes in CACO's piping plover population and reproductive success as measured through the Natural Resource Management Division's ongoing piping plover monitoring and management program.

MONITORING QUESTIONS:
1. Is wrack density a significant predictor of population levels of beach macroinvertebrate species?
2. Does proximity to beach grass influence the composition and structure of beach wrack macroinvertebrate fauna?

3. Can beach and dune dynamics (wrack density, dune vegetation, beach stability) be used to develop predictive models for describing beach macroinvertebrate fauna?
4. Does ORV traffic influence beach macroinvertebrate communities?
5. Can the beach amphipod *Talorchestia longicornis* be used as an indicator of the status of the beach macroinvertebrate community?

STATUS: In Development

A proposal describing the approach to protocol development was prepared in 1998 (Ginsberg and Kluft 1998). Formulation of the monitoring questions and selection of field techniques benefitted from previous work at Fire Island National Seashore and at CACO (Kluft 1997 and Bossung 1998 as cited in Ginsberg and Kluft 1998). Field work for this project was initiated in 2000 and continued through 2002. In 2003 the investigators are planning to focus on processing samples, data analysis, and writing the monitoring protocol.

CITATIONS:

Bossung J. 1997. Cape Cod National Seashore Off-Road Vehicle Monitoring Program: Invertebrate Monitoring, Summer 1997. Draft.

Ginsberg, H. and J. Kluft. 1998. Monitoring the beach macroinvertebrate fauna at Cape Cod National Seashore: assessment of community dynamics. CACO Files. 8pp.

Kluft JM. 1998. Beach macroinvertebrate communities at Fire Island National Seashore. M.S. Thesis. State University of New York, Stony Brook.

WATERBIRDS - COLONIAL WATERBIRDS

PRINCIPAL INVESTIGTORS/COOPERATORS:
Michael Erwin, USGS Pautaxent Wildlife Research Center; funding from USGS-BRD and NPS-CACO NRM

JUSTIFICATION:
CACO supports breeding populations of several species of colonial waterbirds. These include the federally endangered roseate tern (*Sterna dougalli*), Massachusetts Special Concern species common tern (*Sterna hirundo*), least tern (*Sterna antillarum*), and Arctic tern (*Sterna paradisaea*), as well as gulls (*Larus* sp.) and black-crowned night herons (*Nycticorax nycticorax*). Colonial waterbirds depend upon barrier beach habitats for nesting, and estuarine and nearshore habitats for foraging. Their distribution is narrowly restricted to lands and waters immediately along the coast, and while they are largely obligate upon these coastal habitats, they in turn typify them.

Throughout their range colonial waterbird communities have been affected by the combined impacts of habitat loss and alteration, disturbance of breeding birds by human recreation, off-road vehicles, pets, and increased predation by human-enhanced predator populations. At CACO, the distribution and breeding success of these species is affected by both human and natural factors, requiring close monitoring to determine the relative importance of each in any given year and over the longer term. Agents of change such as adverse weather and storms, sea level rise, salt marsh diking, predator overabundance, and recreational use act through geomorphic change, vegetational change, water level change, human and pet disturbance, and increased levels of predation to influence reproductive success and population trends. In order to best determine primary causes of population trends, colonial waterbird monitoring will be interpreted in conjunction with physical-chemical, geomorphic, vegetative, and human activity monitoring data.

MONITORING QUESTIONS:
1. What are the annual breeding population estimates of colonial waterbirds at CACO?
2. How do trends in numbers of colonial waterbirds at CACO compare to trends at the regional (Cape Cod), state, and broader geographic levels?
3. Where are colonies of waterbirds located and how are changes (if any) in colony locations or population numbers related to habitat changes or management activities within CACO?
4. How do annual fecundity and other bioindicators (e.g. contaminant load) of selected species (least and common terns) change through time?
5. Does habitat change or management activity affect annual fecundity?
6. Is local recruitment sufficient to sustain the local breeding colonies, i.e. is CACO or the outer Cape a source or sink for the regional population?

7. Are the methods adequate to detect, for common and least terns, a breeding population change of 25% or more over a 20-year period with a Type I error rate of 0.10 or less (∂ <0.10), with power of 0.80 within CACO?

STATUS: Protocol - In Development; Monitoring - Operational
Colonial waterbird monitoring began in the 1970's as a volunteer activity (Minsky 1981) and eventually became part of the Natural Resource Division's annual operations at CACO (Hake and Schneider 2001). It involves searching all appropriate beach habitat in early spring, locating nesting pairs of plovers, and tracking them through the egg-laying and chick rearing stages. Parameters tracked include numbers of nesting pairs, hatching success, fledging success, productivity, causes of nest failure and chick mortality, as well as the relation of these parameters to management actions and visitor activities. Methods for estimating numbers of nesting pairs vary by species and include counts of incubating birds (least tern), direct counts of nests, corrected by a detectability factor (gulls and terns), and counts of flushed birds (black crowned night heron).

While colonial waterbird monitoring has been ongoing at CACO for many years, a formalized protocol document, particularly one that could also serve the needs of other coastal parks and equivalent sites has not been developed. Erwin et al. (2002) are producing such a document.

CITATIONS:
Hake, M. and Schneider, E. 2001. Monitoring and managing piping plovers and colonial waterbirds at Cape Cod National Seashore 2001. CACO Natural Resource Report 01-02. 47 pp.

Erwin, M., C.J. Conway, S.H. Hadden, J.S. Hatfield, and S.M. Melvin (2002). Waterbird monitoring protocol for Cape Cod National seashore and other coastal parks, refuges, and protected areas. USGS, Patuxent Wildlife Research Center. DRAFT

Minsky, D. 1981. The terns of Cape Cod. Association for the preservation of Cape Cod. Informational Bulletin 9. 34 pp.

WATERBIRDS - PIPING PLOVERS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Michael Erwin, USGS Pautaxent Wildlife Research Center; funding from USGS-BRD and NPS-CACO NRM

JUSTIFICATION:
Piping Plover were listed by the U.S. Fish and Wildlife Service as a Threatened Species in 1986 and monitoring is conducted in accordance with the Atlantic Coast Piping Plover Recovery Plan (USFWS 1996). The Atlantic Coast population of piping plover declined through the combined impacts of habitat loss, disturbance of breeding birds by human recreation, off-road vehicles, pets, and increased predation by human-enhanced predator populations. At CACO, the breeding success of this species is affected by both human and natural factors, requiring close monitoring to determine the relative importance of each in any given year and over the longer term. Agents of change such as adverse weather and storms, sea level rise, predator overabundance, and recreational use act through geomorphic change, human and pet disturbance, and increased levels of predation to influence reproductive success and population trends.

MONITORING QUESTIONS:
1. What is the Piping Plover breeding population size within CACO with respect to the landscape (Cape Cod), state, region, and Atlantic Coast flyway?
2. Is there a detectable trend in breeding pairs on CACO or on Cape Cod over a 10- or 25-year period?
3. Do breeding locations change annually and how much site turnover occurs within CACO?
4. What are the habitat features associated with successful reproduction, or with the greatest densities of breeding birds?
5. Do management actions such as off-road vehicle beach closures, or opening certain beach access points, influence where plovers breed each year?
6. What is the annual fecundity (i.e., number of fledged young per pair)? (Note: the Recovery Plan (USFWS 1996) goal in the "New England recovery unit" is a 5-year average productivity of 1.5 fledged young per pair.)
7. What are the causes of mortality of eggs, young, and adults?
8. Are human activities, including CACO management such as fencing, affecting plover fecundity?

STATUS: Protocol - In Development; Monitoring - Operational
Plover monitoring has been an ongoing annual operation at CACO since 1985 (Hake and Schneider 2001) and is implemented by the Natural Resource Management Division. It involves searching all appropriate beach habitat in early spring, locating nesting pairs of plovers, and tracking them through the egg-laying and chick rearing stages. Parameters

tracked include numbers of nesting pairs, numbers of nesting attempts, hatching success, fledging success, productivity, causes of nest failure and chick mortality, as well as the relation of these parameters to management actions and visitor activities.

While piping plover monitoring has been ongoing at CACO for many years, a formalized protocol document, particularly one that could also serve the needs of other coastal parks and equivalent sites has not been developed. Erwin et al. (2002) are producing such a document.

CITATIONS:

Hake, M. and Schneider, E. 2001. Monitoring and managing piping plovers and colonial waterbirds at Cape Cod National Seashore 2001. CACO Natural Resource Report 01-02. 47 pp.

Erwin, M., C.J. Conway, S.H. Hadden, J.S. Hatfield, and S.M. Melvin. 2002. Waterbird monitoring protocol for Cape Cod National seashore and other coastal parks, refuges, and protected areas. USGS, Patuxent Wildlife Research Center. DRAFT

U.S. Fish and Wildlife Service. 1996. Piping Plover (Charadrius melodus) Atlantic coast population, revised recovery plan. USFWS Regional Office, Hadley, MA.

KETTLE POND WATER QUALITY

PRINCIPAL INVESTIGATOR/COOPERATORS:
John Portnoy, Krista Lee, and Evan Gwilliam, NPS-CACO

JUSTIFICATION:
Most of CACO's kettle ponds are naturally nutrient-poor (mesotrophic to oligotrophic), have low pH and acid neutralizing capacity, and are therefore sensitive to the addition of nutrients and other pollutants. Management concerns include:

- increased human use and accompanying nutrient (phosphorus and nitrogen) loading from a variety of anthropogenic sources including bank and soil erosion, outflow from surrounding septic systems, and visitors and their pets;
- atmospheric deposition of metals, sulfate and nitrate and their effects on pH, alkalinity and sulfur and phosphorus cycling;
- hydraulic alterations, especially stream channelization, which may alter hydrology, trophic structure and native species diversity; and
- fish stocking, for the enhancement of recreational fishing, and its possible effects on pond trophic dynamics.

Research and monitoring of CACO's kettle ponds was initiated in the 1970's and has evolved into a well-developed long-term monitoring program. The objectives of this effort include:

- characterizing pond trophic status;
- developing and implementing repeatable methods of monitoring trophic status and limnological processes to detect important changes;
- describing pond-specific and seasonal limnological and hydrological processes affecting water quality; and
- identifying and developing management actions to mitigate anthropogenic effects.

The selection of monitoring variables and temporal and spatial sampling frequencies is guided by expectations (i.e. hypotheses) regarding the biogeochemical and limnological responses of the ponds to added nutrients (nitrogen and phosphorus), acids (as from "acid rain") or to manipulations of hydrography or of the resident fish community. Monitoring the effects of "external" (extra-watershed) phosphorus loading, for example, on pond trophic status requires data on nutrient status, transparency, and dissolved oxygen. Selection of variables and methods has also greatly benefited from periodic technical reviews by scientists and resource managers with expertise and experience in Cape Cod limnology, hydrology and biogeochemistry.

Analysis and interpretation of pond water quality data is being integrated with the results of hydrological, meteorological and atmospheric monitoring to assess the role of atmospheric deposition and local ground water flow patterns in pond limnological processes. We expect the information produced by the hydrology, ground water quality, aquatic invertebrate, amphibian, and freshwater fish protocols, together with the pond water quality data, will help us address these concerns.

MONITORING QUESTIONS:

1. What are the long-term trends in acidity and acid-neutralizing capacity?
2. How do productivity and ionic composition during the brief well-mixed period (spring) vary from pond to pond and across years?
3. How do the depth and duration of oxygen depletion in deep waters vary from pond to pond and across years during the spring-to-fall period of stratification?
4. How do ponds vary from one another and over time during periods of maximum productivity and hypolimnetic hypoxia (late summer)?
5. Do management actions, like shoreline stabilization, result in improved water quality?
6. As land use within pond watersheds changes, what is the response of water quality constituents?

STATUS: Protocol - Completed; Monitoring - Operational

Monitoring comprises four sub-programs addressing the monitoring questions above:

1. April, July and October pH and alkalinity survey of all 20 ponds. *Sampling of pH and alkalinity three times per year (April, July and October) tracks long-term trends in acidity and acid-neutralizing capacity, both of which can vary seasonally*.
2. Spring survey of all ponds for transparency, nitrate, ammonium, total phosphorous, total nitrogen, chlorophyll α, and major ions (chloride, sulfate, calcium, magnesium, potassium, sodium). *This is a "snap-shot" of pond productivity and ionic composition during the brief spring well-mixed period.*
3. Summer (May through October) biweekly sampling of ten top-priority ponds for stratification, dissolved oxygen and transparency. *The prime objective is to document the depth and duration of oxygen depletion in deep waters throughout the spring-to-fall period of stratification.*
4. August survey of all 20 ponds for stratification, dissolved oxygen, chlorophyll α, nitrate, ammonium, total nitrogen, and total phosphorous. *This is an annual characterization of the degree of eutrophication of all 20 ponds during the worst-case, late-summer period.*

These monitoring procedures are described in the kettle pond water quality monitoring protocol (Portnoy et al. 2001).

High inter- and intra-annual variability requires that pond water quality profiles be collected biweekly during stratification and that sampling be conducted annually. Results to date indicate little recent change in indicators of eutrophication or acid balance; however, human use, shoreline residency, and atmospheric pollution continue.

CITATIONS:

Portnoy, J. , J. Cote, and K. Lee. 2001. Water Quality Monitoring Protocol for Kettle Ponds of Cape Cod National Seashore. CACO files. 53pp.

KETTLE POND VEGETATION

PRINCIPAL INVESTIGATOR/COOPERATORS:
Stephen Smith and John Portnoy, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:
Due to extremely low nutrient availability, lack of base cations, and low pH buffering capacity, many kettle ponds within CACO are highly oligotrophic and support unique assemblages of flora and fauna that are adapted to such conditions. In fact, numerous species of rare plants (some listed as State Endangered, Threatened, Species of Special Concern, and Watch) are primarily found in this environment. However, there is evidence that anthropogenic stresses, such as eutrophication, are impacting the character of certain ponds (Portnoy et al. 2001). External nutrient sources include bather urination, wastewater disposal systems of surrounding private homes, acid rain, shoreline erosion, and runoff from paved surfaces such as parking lots and roads. Altered hydrology from increased groundwater withdrawal also may impact pond chemistry and biota (Schneider 1994). Like other habitats within CACO, several aspects of global change (e.g., ultraviolet radiation, elevated temperature, etc.) may be influencing these systems as well. With increased visitor use each year, kettle ponds must be closely monitored so that negative changes can be detected early and, subsequently, management alternatives considered.

The protocol is most closely linked with monitoring of other waterbody types such as woodland vernal pool and dune slack wetland protocols. Information provided by the forest monitoring protocol will be helpful in evaluating inputs of organic matter and sediment from kettle pond basins.

MONITORING QUESTIONS:
1. How does vegetation structure and function relate to hydrology and trophic status of kettle ponds?
2. Which physical, chemical, and biological factors have the greatest influence on spatial and temporal variability in vegetation?
3. Can temporal and spatial vegetation patterns and process be used to assess anthropogenic impacts to kettle ponds?

STATUS: In Development
In 1995, Roman et al. (2001) conducted a thorough analysis of vegetation, water quality, and soil properties at five kettle ponds within CACO. The results suggested that plant species composition and the relative abundance of certain functional groups (i.e., floating leaf and rosette-type macrophytes) were well-correlated with trophic status. Notwithstanding, there may be other measures of plant physiology and/or phenology that can provide earlier warnings of change before the system reaches a stage where

manifestations of inter-specific competition occur. In this regard, leaf and root tissue nutrient concentrations, leaf morphology, and plant heights of key emergent species have been used as indicators of enrichment in oligotrophic wetlands (Craft and Richardson 1994, Miao and Sklar 1998, Smith and Newman 2001). Epiphytic algae (periphyton), which have increased in abundance in recent years according to anecdotal observations, may be another good indicator of nutrient and hydrologic impacts (McCormick and Stevenson 1998). Finally, the horizontal expansion of plant stands will be monitored by methods yet to be developed in order to document changes in overall vegetation cover.

In terms of revisions to the existing methodology, the line intercept method used to quantify vegetative cover in the 1995 study will be compared to, and potentially replaced by, the modified point intercept method as described by Roman et al. (2001). Some level of targeted monitoring is likely to be incorporated into the protocol as a means to assess impacts from point sources (e.g., eroded trails, residences). Finally, the value of seedling emergence assays will be assessed from the standpoint of predicting future vegetative trends, the potential for establishment of exotics, and developing models of restoration pathways (Smith and Kadlec 1984, Leck and Simpson 1987).

CITATIONS:

Craft , C.B. and C.J. Richardson. 1994. Response of Everglades plant communities to nitrogen and phosphorus additions. Wetlands 15:258-271.

Leck, M.A. 1989. Wetland Seedbanks. Pages 283-305 in M.A. Leck, V.T Parker, and R.L. Simpson, editors. Ecology of Soil Seedbanks. Academic Press Inc., San Diego, CA.

McCormick, P. and R. Stevenson. 1998. Periphyton as a Tool for Ecological Assessment and Management in the Florida Everglades. Journal of Phycology 34:726-733.

Miao, S. L. and F. H. Sklar. 1998. Biomass and nutrient allocation of sawgrass and cattail along a nutrient gradient in the Florida Everglades. Wetland Ecology and Management 5:245-263.

Portnoy, J., M. Winkler, P. Sanford, and C. Farris. 2001. Kettle Pond Data Atlas: Paleoecology and modern water quality. Cape Cod National Seashore, National Park Service, U.S. Department of Interior. 119pp.

Schneider, R. 1994. The role of hydrologic regime in maintaining rare plant communities of New York's coastal plain pondshores. Biological Conservation 68:253-260.

Smith, L.M. and J.A. Kadlec. 1984. Seedbanks and their role during drawdown of a North American marsh. Journal of Applied Ecology 20:673-684.

Smith, S.M. and S. Newman. 2001. Growth of southern cattail (*Typha domingensis*, Pers.) in response to fire-related soil conditions in a northern Everglades marsh. Wetlands 21: 363-369.

DUNE SLACK VERNAL WETLANDS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Stephen Smith and John Portnoy, NPS-CACO; funding from NPS-WRD

JUSTIFICATION:
The northern tip of Cape Cod was formed soon after glacial retreat ca.18,000 years ago when longshore currents began transporting eroded materials from Atlantic-side beaches in a northward direction. Concurrently, wind carried sand grains inland and the peninsula was gradually extended. Over time, mature forest became established on the landscape though European settlers subsequently engaged in clear cutting and grazing practices that eliminated much of this community and effectively destabilized the soil surface. Since the discontinuation of these activities in the 1800s, the area has evolved into what is known today as the Province Lands - an extensive system of dunes variably covered by early successional plant communities interspersed with new and remnant pine forest.

Where interdunal depressions approach or intersect the groundwater table for at least part of the year distinctive hydrophytic plant communities occur. These wetlands, termed "dune slacks" are virtual oases in what is otherwise an extremely harsh, dry environment. Relatively little is known about the ecology of dune slacks within CACO and how they may respond to natural and anthropogenic stress. From a landscape perspective, dune slacks contribute to ecosystem diversity within the Province Lands and CACO as a whole. The loss of dune slack habitat worldwide further accentuates the need for their protection at CACO. In addition, these areas are very popular with visitors, as they possess aesthetic qualities that are a valued component of the Province Lands scenery.

Dune slacks within CACO face a number of realized and potential threats. Increased demand for freshwater from wells adjacent to CACO boundaries will depress groundwater elevations (Martin 1993). Urban development also carries with it the risk of groundwater contamination from a variety of pollutants (Winkler 1994). Such alterations to hydrology and water quality may directly impact the growth and survival of dune slack biota. Compounding this problem over the long term is accelerated sea level rise, which will move the freshwater/saltwater interface in a landward direction. Moreover , atmospheric conditions related to acid deposition, tropospheric ozone, ultraviolet-b radiation, and global warming may push certain species past their thresholds of stress tolerance.

Dune slacks are also threatened by a number of exotic plant species that have the potential to impact the resident biota. Dense stands of common reed (*Phragmites australis*) have already colonized several wetlands in the western reaches of the Province Lands and purple loosestrife (*Lythrum salicaria*) has been found growing along the shorelines of two permanent ponds in the area. Over longer time-scales, the process of vegetation succession may contribute to the loss of dune slack habitat as wetlands turn into shrublands and, eventually, to woodlands. With improved sand stabilization and soil development, opportunities for the creation of new dune slacks by both episodic events (i.e., dune blowouts) and persistent processes (i.e., sand transport) will be greatly diminished. Furthermore, there is reason to believe that rates of succession are being accelerated by atmospheric deposition of nitrogen in rain and fog (Sival and Strijkstyra-Kalk 1999). Finally, the climax stage of succession itself (i.e., the establishment of mature forest) is expected to increase the rates of evapotranspiration and, consequently, depress the water table (Van Dijk and Grootjans 1993).

Information produced by the hydrology monitoring effort will be helpful for interpretation of the hydrologic data collected for dune slacks. This protocol is closely linked with herpetofauna and freshwater aquatic invertebrate monitoring as the reproduction and survival of Spadefoot toad (*Scaphiopus holbrookii*), Fowler's toad (*Bufo fowleri*), and numerous invertebrate species are dependent upon the continued existence of dune slacks. There is also a close link with dune grasslands, which is typically the adjacent community type.

MONITORING QUESTIONS:

1. How does vegetation structure and function vary temporally and spatially within dune slack vernal wetlands at CACO?
2. Which physical, chemical, and biological factors have the greatest influence on spatial and temporal variability of dune slack plant communities?
3. What effects will ground water withdrawal have on dune slack habitat?

STATUS: In Development

A proposal to inventory and intensively study dune slacks was funded by the Water Resources Division in 2002. A comprehensive work plan to carry out this effort over the course of 2 years (FY03/04) was completed in September 2002. The work will involve mapping of dune slack habitat, developing GIS-based variables to characterize slack position and the surrounding terrain, and collecting data on elevation, microtopography, hydrology, water quality, soil properties, and vegetation. It is expected that this study will serve as a basis for a long-term dune slack monitoring protocol.

CITATIONS:

Martin, L. 1993. Investigation of the effects of ground water withdrawals from the Pamet and Chequesset aquifers, Cape Cod National Seashore. Technical Report NPS/NRWRD/NRTR-93/14. National Park Service, Water Resources Division, Fort Collins, CO.

Sival, F.P and M. Strijkstyra-Kalk. 1999. Atmospheric deposition of acidifying and eutrophicating substances in dune slacks. Water, Air, and Soil Pollution 116:461-477.

Van Dijk, H.W.J. and A.P. Grootjans. 1993. Wet dune slack: decline and opportunities. Hydrobiologia 265:281-304.

Winkler, M.G. 1994. Modern limnology of the Provincelands ponds for comparison with recent changes in the biota of Duck and Bennett ponds adjacent to the Provincetown municipal landfill. Technical report NPS/NAROSS/NRTR-94/20. Department of the Interior, National Park Service, North Atlantic Region, Natural Resources Management and Research, Boston, MA.

PROVINCE LANDS POND VEGETATION

PRINCIPAL INVESTIGATOR/COOPERATORS:
Stephen Smith and John Portnoy, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:
Within the Province Lands region of CACO there are a number of permanent freshwater ponds that are structurally, biologically, and geologically different from kettle ponds (Winkler 1992). They also differ from dune slack vernal wetlands because they do not exhibit seasonal drydown. Similar to these other systems, however, the Province Lands ponds are generally acidic and oligotrophic and harbor an extraordinary assemblage of plants and animals, many of which are listed as State Threatened or Endangered.

Like other freshwater environments at CACO, the ecological integrity of the Province Lands ponds is threatened by alterations in hydrology (Schneider 1994) and contaminants of water quality (Winkler 1994). Other potential stresses include acid rain, air pollution, succession, and the proliferation of exotic species such as purple loosestrife (*Lythrum salicaria*) and common reed (*Phragmites australis*), which have the potential to completely displace native species. Because of the sensitive nature of the Province Lands ponds, a rigorous monitoring program is an indispensable element of effectively managing this resource.

The Province Lands ponds are similar in many respects to CACO's kettle ponds and dune slack vernal wetlands. This protocol will benefit from and, conversely, provide information for assessments of these other waterbodies.

MONITORING QUESTIONS:
1. How does vegetation structure and function vary temporally and spatially within the Province Lands ponds at CACO?
2. Which physical, chemical, and biological factors have the greatest influence on spatial and temporal variability in the vegetation of the Province Lands ponds?
3. Do temporal and spatial vegetation patterns suggest anthropogenic impacts to these ponds?
4. Are changes in the relative proportions of functional groups (e.g., decline in insectivorous plants) being observed?

STATUS: In Development
This protocol is in the initial phase of development with an emphasis on data mining and information gathering. Notwithstanding, it is anticipated that the general approach and methodology will essentially mirror those of dune slack vernal wetland and kettle pond protocols.

CITATIONS:

Schneider, R. 1994. The role of hydrologic regime in maintaining rare plant communities of New York's coastal plain pondshores. Biological Conservation 68:253-260.

Winkler, M. 1992. Development of parabolic dunes and interdunal wetlands in the Provincelands, Cape Cod National Seashore. Society for Sedimentary Geology 48:57-64.

Winkler, M.G. 1994. Modern limnology of the Provincelands ponds for comparison with recent changes in the biota of Duck and Bennett ponds adjacent to the Provincetown municipal landfill. Technical report NPS/NAROSS/NRTR-94/20. Department of the Interior, National Park Service, North Atlantic Region, Natural resources Management and Research, Boston, MA.

WOODLAND VERNAL POOL VEGETATION

PRINCIPAL INVESTIGATOR/COOPERATORS:

Stephen Smith and John Portnoy, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:

Woodland or forested vernal pools are fundamentally different from dune slack vernal wetlands in that the surrounding terrain has attained a much later successional stage. Accordingly, both the amount and chemical composition of inorganic and organic matter inputs from basin slopes may be substantially different. Woodland vernal pools also exhibit some of the highest variability in plant community composition, a characteristic that has yet to be adequately explained. A number of rare insectivorous plant species are found in vernal pools and several amphibians, such as wood frogs (*Rana sylvatica*) and spotted salamanders (*Ambystoma maculatum*), only breed in this environment (Portnoy 1987, 1990). Vernal pools also harbor many aquatic invertebrates (Godfrey et al. 1999) and are visited by migrating birds. Acid rain, polluted runoff, and altered hydrology have been identified as the most significant threats to vernal pools at CACO.

This protocol has critical linkages with forest monitoring since woodland vernal pools are surrounded by treed landscapes. Many elements of this protocol correspond with those of dune slack vernal wetlands. Because vegetation determines much of the physical structure of vernal pool habitat, freshwater aquatic invertebrate and amphibian monitoring will benefit greatly from this protocol.

MONITORING QUESTIONS:

1. What explains the high level of disparity in plant species composition among woodland vernal pools?
2. Will groundwater withdrawal significantly affect vernal pool plant communities?
3. Which physical, chemical, and biological factors most influence vernal pool vegetation dynamics?
4. How are these waterbodies changing over time and are the changes related to anthropogenic stress?
5. What kinds of management strategies are needed to preserve this habitat?

STATUS: In Development

A detailed study of three vernal pools in Eastham was conducted in 1997-1999. Analysis of vegetation, soils, hydrology, and water chemistry revealed that depth to water table was one of the most important variables regulating plant species composition. However, the results also suggested a need to further explore reasons for the vast physiognomic differences among pools. In 2005, the three previously studied vernal pools will be resampled in addition to 6 others in the area (total of 9). The vegetation protocol will follow that used in the 97-99 work although additional parameters may be added.

Lessons learned from the dune slack vernal wetland study (03-04) will be applied as appropriate.

CITATIONS:

Godfrey, P.J., K. Galluzo, N. Price, J. Portnoy. 1999. Water resources management plan, Cape Cod National Seashore, Massachusetts. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA.

Portnoy, J.W. 1987. Vernal ponds of the Cape Cod National Seashore: Location, water chemistry, and *Ambystoma* breeding biology. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA

FRESHWATER AQUATIC INVERTEBRATES

PRINCIPAL INVESTIGATOR/COOPERATORS:

David Foster and Elizabeth Colburn, Harvard Forest; funding from NPS-CACO I&M

JUSTIFICATION:

Freshwater lakes, ponds and wetlands, and the plants and animals that they support, are among CACO's most important natural resources. The development of an inventory of the biological resources of CACO's freshwaters, and the establishment of a program of long-term biological monitoring to detect changes in water quality and quantity are high priorities for the National Park Service (Godfrey al. 1999). Freshwater macroinvertebrates can be used to evaluate change in lakes, ponds and wetlands over time (Hynes 1960, Warren 1971, Rosenberg and Resh 1993). Lake classification, based on the composition of the aquatic invertebrate community, developed as a field more than a century ago and there is renewed interest in lake typology using aquatic benthic (bottom-dwelling) fauna (Saether and Schnell 2002). The identification of biological reference conditions, consisting of defined assemblages of aquatic invertebrates associated with particular suites of physical and chemical conditions and/or levels of disturbance, is widely used in the classification and assessment of streams (Resh and Unziker 1975, Resh et al. 1995), and is being applied to the bioassessment of freshwater wetlands nationwide (Danielson 1998).

MONITORING QUESTIONS:

1. What is the status of and trends in the invertebrate species composition of CACO's freshwater systems?
2. How do changes in the aquatic invertebrate fauna relate to environmental stressors of management concern – chiefly ground water withdrawal (pond level, pool flooding frequency and duration), eutrophication, sediment input and alterations in acid/base balance due to surrounding land cover changes and from atmospheric deposition?

STATUS: In Development

Near the close of FY2002 a proposal was submitted, reviewed and accepted. A cooperative agreement has been established between NPS and Harvard University for this project. Planning is underway for field work to be conducted in 2003 and 2004.

CITATIONS:

Danielson, Thomas J. 1998. Wetland Bioassessment Fact Sheets. EPA843-F-98-001. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division, Washington, DC.

Foster, D.R. and E.A. Colburn. 2002. Proposal for Establishing a Long-term Monitoring Protocol for Freshwater Macroinvertebrates at the Cape Cod National Seashore. Harvard Froest, Harvard University. 20 pp.

Godfrey, PJ, K, Galluzzo, N. Price and JW Portnoy. 1999. Water Resources Management Plan, Cape Cod National Seashore.

Hynes, H.B.N. 1974. The Biology of Polluted Waters. University of Toronto Press. Toronto. 202 pp.

Resh, Vincent H. and John D. Unziker. 1975. Water qualtiy monitoring and aquatic organisms: the importance of species identification. Journal of the Water Pollution Control Federation 47(1): 9-19.

Resh, Vincent H., Richard H. Norris, and Michael T. Barbour. 1995. Design and implementation of rapid bioassessment approaches for water resource monitoring using benthic macroinvertebraes. Australian Journal of Ecology 20: 108-121.

Rosenberg, David M. and Vincent H. Resh (eds.). 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York. 488 pp.

Saether, Ole A. and O. A. Schnell. 2002. Lake typology revisited. An updated version of an old concept. Annual meeting, North America Benthological Society, Pittsburgh, PA, May 31, 2002. Abstract.

Warren, Charles E. 1971. Biology and Water Pollution Control. Philadelphia: WB Saunders Co. 434 pp.

FRESHWATER FISH

PRINCIPAL INVESTIGATOR/COOPERATORS:
Martha Mather, USGS-BRD, University of Massachusetts; funding from the NPS-NRPP

JUSTIFICATION:
Freshwater fish provide recreation for both anglers and non-anglers and act as key predators in aquatic food webs. However, hydrologic alterations, groundwater withdrawal, atmospheric deposition of metals and acidity, nutrient loading from adjacent development, exotic fish introductions and associated management actions (including past additions of lime and rotenone), and recreational fishing pressure complicate the management of these populations at CACO. Therefore there is an urgent need to establish a program of long-term monitoring that tracks fish species composition, size, abundance, and trophic relationships along with environmental variables affecting the quality of fish habitat within permanently flooded freshwaters in the Park. This protocol is linked to hydrological, amphibian, kettle pond water quality, kettle pond vegetation, estuarine nekton and aquatic invertebrate protocols.

MONITORING QUESTIONS:
1. What is the current composition of freshwater fish communities in all CACO habitats?
2. How do these communities change with season and over the long term (decades)?
3. How do observed fish species and size/age classes fit into the trophic structure considering predation, planktivory, migratory behavior, zooplankton composition and abundance and benthos?
4. What are the processes governing fish species composition, including abiotic, biotic, landscape, stocking and management history, and fishing pressure?

STATUS: In Development
Protocol development for CACO is part of a larger project to inventory and develop monitoring protocols for seven northeastern NPS units. A proposal for the inventory and protocol development was prepared in 1998 (Mather 1998). A draft report describing the results of the inventory was completed in 2002.

CITATIONS:
Mather, M.E. 1998. Patterns and processes for freshwater fish distribution in northeastern National Parks: Inventory, monitoring, and a model of governing processes. Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts. 22 pp.

POND-BREEDING AMPHIBIANS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Peter Paton, University of Rhode Island; Robin Jung, USGS Patuxent Wildlife Research Center; funding from USGS-BRD

JUSTIFICATION:
Amphibians are a diverse group occupying a broad range of aquatic and terrestrial habitats and exhibiting a wide range of life history variation. As mid-level predators they are important components of energy flow and often dominate vertebrate biomass (Burton and Likens 1975). Due to their highly permeable skin and egg masses, amphibians are dependent upon aquatic habitats or environmental moisture, and highly sensitive to pollutants and toxins. While their high degree of sensitivity makes them excellent indicators of environmental quality (Vitt et al. 1990), this sensitivity has been responsible, at least in part, for reports of declines throughout the world. Other factors responsible for reported declines include habitat loss and degradation, invasive species, disease, unsustainable use, and global climate change (Wake 1991, Gibbons and Stangel 1999).

CACO supports 11 amphibian species, including the state threatened eastern spadefoot toad (*Scaphiopus holbrooki holbrooki*) and the four-toed salamander (*Hemidactylium scutatum*), a species of special concern. The eastern spadefoot toad is an obligate of pitch pine barrens/coastal oak woodland interspersed with vernal pools, and CACO supports one of the most significant populations in the Northeast. Four-toed salamanders are an obligate of red maple/cedar swamps and vernal pools. At CACO amphibians comprise a high proportion of the vertebrate biomass in kettle ponds and vernal pools. Species such as the spotted salamander (*Ambystoma maculatum*) and wood frog (*Rana sylvatica*) breed exclusively in vernal pools and are sensitive to low pH and degradation in water quality.

While the abundance, composition and species richness of amphibian communities naturally change over gradients in precipitation, soil moisture, and vegetation type, there are, additionally, a variety of ways in which amphibian communities may change in response to human activities. At CACO, these range from broad regional effects of atmospheric pollution (acidic and mercury deposition) to more localized effects from changes in land use (increased residential development), leading to habitat fragmentation, increased groundwater withdrawal altering pond hydroperiods, road mortality on migrating and breeding populations, exotic species introductions, and pollution from pesticide, nutrient and road runoff.

Given the strong relationship of amphibian distribution and abundance to vegetation, meteorology, atmospheric deposition, hydrology, and water quality, amphibian monitoring will incorporate data from these protocols in its analyses.

MONITORING QUESTIONS:

1. What species of amphibians are breeding at CACO and what are their distribution and abundance?
2. What are the temporal trends in the occurrence, distribution and abundance of amphibians at CACO?
3. Do changes to wetland hydrography or hydroperiod induced by groundwater withdrawal, sea level rise, or climatic change alter amphibian community composition or species abundance?
4. Are long-term changes in climate variables such as temperature, precipitation, UV-B radiation, surface water acidification, and mercury deposition affecting life history parameters of amphibians, such as breeding phenology, rates of growth and development, or reproductive success?
5. How do temporal trends in the occurrence, distribution and abundance of amphibians at CACO relate to temporal trends in environmental variables such as hydroperiod, vegetation, pH, rainfall, and temperature?
6. Are amphibian community structure or abundance affected by road mortality?

STATUS: Protocol - In Development; Monitoring - To Be Initiated in 2003
Several potential monitoring methods were tested in 2001. This determined that the most effective and practical methodologies for monitoring pond–breeding amphibians were anuran call counts and vernal pond egg mass counts (Paton et al. 2002). Implementation will begin in 2003. Anuran call counts will be conducted at 30 sites distributed across the range of freshwater habitat types present at CACO, as well as distributed geographically. Call counts will occur at night, on a weekly basis, from early spring to early summer. Egg mass counts (focused on wood frog and spotted salamander) will be conducted at 30 vernal ponds throughout the park. Sites selected are distributed throughout the park (to account for patterns of species distribution) and represent a range of hydroperiods, dominant vegetation, pond pH, and road density/proximity (Jung, pers comm.)

CITATIONS:

Burton, T.M and Likens, G.E. 1975. Salamander populations and biomass in the Hubbard Brook experimental forest, New Hampshire. Copeia. 1975:541-546.

Gibbons, J. W. and Stangel, P.W. (coordinators). 1999. Conserving amphibians and reptiles in the new millenium. Proceedings of the partners in amphibian and reptile conservation (PARC) conference. 1999. Savannah River Ecology Laboratory Herp Outreach Publication#2. Aiken SC.

Jung, Robin (pers comm, 2002). USGS, BRD. Wood frog and spotted salamander egg mass counts and percent vernal pools occupied by amphibian species on DOI lands in the Northeastern United States. 18 pp.

Paton, P.W.C, Timm, B., and Tupper T.A.. 2002. Monitoring Pond Breeding Amphibians: A Protocol for the Long-Term Coastal Ecosystem Monitoring Program At Cape Cod National Seashore. (DRAFT) 98pp.

Vitt, L.J., J.P Caldwell, H.M. Wilbur, and D.C. Smith. 1990. Amphibians as harbingers of decay. BioScience 40:418.

Wake, D. B. 1991. Declining amphibian populations. Science 253:860.

WATERBIRDS - MARSH BIRDS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Michael Erwin, USGS Pautaxent Wildlife Research Center; funding from USGS-BRD

JUSTIFICATION:
CACO contains extensive wetlands that provide breeding and migratory resting and feeding habitat for several species of secretive rails, bitterns, and related species. While these species may serve as bioindicators of the quality of marsh habitats (Erwin et al 2002), loss and degradation of wetland habitats has resulted in many of these species being listed by states in the Northeast as endangered, threatened, or special concern (Therres 1999). At CACO, marsh bird species include sora (*Porzana carolina*), Virginia rail (*Rallus limicola*), king rail (*Rallus elegans* – State Threatened), pied-billed grebe (*Podilymbus podiceps* – State Endangered), American coot (*Fulica americana*), American bittern (*Botaurus lentiginosus* – State Endangered), and least bittern (*Ixobrachus exilis* – State Endangered).

Marsh birds at CACO occur primarily in diked salt marshes and herbaceous-dominated freshwater wetlands, two habitats with great potential for change over time. In addition to management actions to restore tidal flow to diked salt marshes, freshwater marshes are potentially subject to changes in water level and vegetation as a result of groundwater withdrawal, nutrient enrichment, and alien plant invasion. These agents of change, as well as human recreation, all have the potential to alter the original habitat quality and thus the distribution and abundance of marsh birds at CACO. Given that marsh birds are indicative of intact, unfragmented, undisturbed marshlands, their monitoring here will serve as an indicator of marsh habitat quality. To better understand primary causes of marsh bird population trends at CACO, monitoring of marsh birds will be integrated into broader monitoring of physical-chemical, hydrologic, vegetative, and human activity parameters of marsh systems.

MONITORING QUESTIONS:
1. What is the distribution, frequency of occurrence, and relative abundance of these secretive rails, bitterns, and other marsh species within CACO?
2. What are the trends in distribution, frequency of occurrence, and relative abundance of these species within CACO?
3. Do changes in habitat (such as those associated with marsh restoration), surrounding land use, or recreational/management activities on CACO wetlands influence distribution, frequency of occurrence or relative abundance of marsh birds at CACO?

STATUS: Protocol - In Development; Monitoring - To Be Initiated in 2003
Field testing of tape playback methods was conducted in 1999 and 2000. The results indicated that monitoring of freshwater habitats in breeding season produced most useful

data. A protocol (Erwin et al. DRAFT) has been drafted and is undergoing review and revision. The recommended protocol for CACO will call for use of tape playback method during breeding season at seven freshwater/diked salt marsh sites. A total of 40 sample points will be surveyed 3-4 times to provide data on occurrence, distribution, relative abundance, and frequency of occurrence. At CACO, marsh bird monitoring will be conducted every 3-5 years. Due to low rate of encounters and frequency of monitoring, data will probably not support statistical analysis of trends. First season of implementation is planned for 2003.

CITATIONS:

Erwin, M., C.J. Conway, and S.H. Hadden. 2002. Species occurrence of marsh birds at Cape Cod National Seashore, Massachusetts. Northeastern Naturalist 9(1): 1-12.

Erwin, M., C.J. Conway, S.H. Hadden, J.S. Hatfield, and S.M. Melvin (DRAFT) . Waterbird monitoring protocol for Cape Cod National seashore and other coastal parks, refuges, and protected areas. USGS, Patuxent Wildlife Research Center. DRAFT 2002

Therres, G. 1999. Wildlife species of regional conservation concern in the northeastern United States. Northeast Wildlife 54:93-100.

LICHENS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Stephen Smith and Krista Lee, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:
Lichens can be found in all terrestrial habitats of CACO and in some places, such as interdunal flats within the Province Lands dunes, they are the predominant life-form. Some lichens have the ability to fix atmospheric nitrogen and are therefore important in successional processes. Because they have no root system and receive virtually all their nutrition from precipitation, they have long been used as sensitive bioindicators of air pollution (Baddeley 1973). Furthermore, there are species such as *Hypogymnia physodes* that are widely distributed across the country, which allows for comparisons with other parks (Wetmore 1985a,b). Because CACO is plagued by high levels of acid precipitation and ozone, the development of a lichen inventory and monitoring protocol appears an essential component of natural resource management.

This protocol is closely associated with dune grassland, forest, heathland, and atmospheric deposition monitoring.

MONITORING QUESTIONS:
1. What ecological role do lichens play in the ecology of forest, heathland, and dune systems?
2. How does lichen cover (biomass) and species composition vary across the CACO landscape and how is it changing over time?
3. What are concentrations of certain elements in lichen tissues telling us about air pollution levels and trends at CACO?

STATUS: In Development
This protocol is in the early research phase of development, which involves the acquisition of relevant background information and selection of appropriate methods for testing.

CITATIONS*:*
Baddeley, M.S., B.W. Ferry and E.J. Finnegan. 1973. Sulphur dioxide and respiration in lichens. pp. 229-313. In: Ferry, B.W., M.S. Baddeley and D.L.Hawsworth (eds.), Air Pollution and Lichens. Althone Press, London.

Wetmore, C.M. 1985a. Lichens and air quality in Isle Royal National Park: Final Report. NPS Contract CX 0001-2-0034. Department of the Interior, National Park Service, Houghton, MI.

Wetmore, C.M. 1985b. Lichens and air quality in Sequoia National Park. Final Report, NPS Contract CX 0001-2-0034. U.S. Department of the Interior, National Park Service, Sequoia National Park, Three Rivers, CA

DUNE GRASSLAND VEGETATION

PRINCIPAL INVESTIGATOR/COOPERATORS:
Stephen Smith, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:
Large areas of CACO are comprised of extensive sand dunes covered by early successional plant communities. The dynamics of soil stabilization and plant succession in this environment are of considerable interest to the Seashore as these processes have a major influence on erosion and shoreline change. In terms of vegetation development in dune grasslands, it is quite possible that nitrogen deposition in the form of acid rain and fog may be accelerating rates of succession – a phenomenon that has been documented in European dune systems (Sival and Strijkstyra-Kalk 1999). In contrast, increased human visitation to these areas may be reversing successional trends through direct physical disturbance. By monitoring dune grasslands, we are afforded a unique opportunity to observe all phases of vegetation succession and the mechanisms that drive or hinder the process.

For certain species of wildlife, dune grasslands have the kind of vegetation structure that is ideal for their particular niche. The grasshopper sparrow, vesper sparrow, and Northern harrier, all of which are classified as State Threatened, are heavy users of dune grasslands (Kearney and Cook 2001). This protocol will help managers to make informed decisions regarding habitat protection for these species.

This habitat borders salt marshes, forests and woodlands, dune slack vernal wetlands, Province Lands ponds, and heathlands. Accordingly, dune grassland monitoring data will be useful in conducting assessments of many other systems, and will benefit from information collected through protocols addressing atmospheric deposition and visitor impacts.

MONITORING QUESTIONS:
1. How do plant communities vary structurally and compositionally across dune grassland habitat?
2. How are plant communities changing across dune grasslands and at what rate?
3. What are the key factors regulating plant community development in this system?
4. Are anthropogenic nitrogen inputs accelerating rates of succession?
5. What kinds of management strategies are needed to preserve this habitat?

STATUS: In Development
Previous work in CACO's dune grasslands has been limited, for the most part, to surveys targeting off-road vehicle impacts and re-vegetation efforts (Zaremba et al. 1979, Knutson 1980, Smith and Mello 1984). However, many elements of these studies can be

applied to a long-term monitoring protocol. The point-intercept method (Barrett 1999, Roman et al. 2001) will be used to sample vegetation along previously and newly established transects. In addition, plant tissue nutrient concentrations (nitrogen in particular) and heights of key species will be incorporated into the sampling regime - two parameters that may indicate trends on a more sensitive level than plant cover and species composition. To address visitor impacts, it would be desirable to sample two kinds of sites - those that are subject to foot traffic and those that are undisturbed. For the latter it may be necessary to use exclosures to prevent assess or place sites in remote locations. Potential study areas for dune grassland monitoring can be found along the entire stretch of Atlantic-side beaches (e.g., Marconi Area, Coast Guard Beach, Nauset Beach) as well as Great Island on Cape Cod Bay.

CITATIONS:

Barrett, N.E. 1999. Proposed sampling protocols to be tested for a vegetation survey and monitoring program at Cape Cod National Seashore. U.S. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA.

Kearney, S.B. and R.P. Cook. 2001. Status of grassland and heathland birds at Cape Cod National Seashore, Massachusetts. Technical report NPS/BSO-RNR/NRTR/2002-3. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA.

Knutson, P.L. 1980. Experimental dune restoration and stabilization, Nauset Beach, Cape Cod National Seashore, Massachusetts. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA.

Roman, C.T., M-J. James-Pirri, J.F. Heltshe. 2001. Monitoring salt marsh vegetation: a protocol for the long-term coastal ecosystem monitoring program at Cape Cod National Seashore. U.S. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA.

Sival, F.P and M. Strijkstyra-Kalk. 1999. Atmospheric deposition of acidifying and eutrophicating substances in dune slacks. Water, Air, and Soil Pollution 116:461-477.

Zaremba, R.E. 1979. The ecological effects of off-road vehicles on the beach/backshore (drift line) zone in Cape Cod National Seashore, Massachusetts. UM-NPSCRU Report # 29. The Environmental Institute. University of Massachusetts, Amherst, MA.

COASTAL HEATHLANDS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Tom Husband, URI Department of Natural Resources Science; Evan Gwilliam, NPS-CACO; funded by USGS-BRD and NPS-CACO I&M

JUSTIFICATION:
The coastal grasslands and heathlands of North America are rapidly disappearing. Heathlands are considered to be globally-rare, and the endemic and obligate species associated with this declining habitat are correspondingly sensitive. CACO supports most of the remaining heathlands on Cape Cod. Due to the erosion of coastal bluffs, the cessation of agriculture, and forest succession, from 1962 to 1985, 62% of the heathlands contained within the park have been lost (Carlson et al. 1992). This recognized significant loss of heathlands, represents not only a significant threat to one of CACO's most diverse habitats, but also indicates a potential significant decline in the populations of endangered endemic plant and animal species (Dunwiddie et al. 1996).

The 1999 Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore proposed development of a monitoring protocol that will detect the response of heathland vegetation structure and species composition to natural processes, site specific processes and regional factors. The protocol objectives are to:

- quantify characteristics common to coastal heathlands; topography, soil resources and microclimates;
- quantify coarse scale disturbance regime and site history in terms of size, severity, frequency and dispersion on the landscape; and
- quantify coastal heathland vegetation structure, dominant physiology, floristic composition and cover across gradients of landscapes representing a range in habitats and site history.

The coastal heathland monitoring program at the CACO will establish a network of permanent plots that tracks the influence of humans and explains long-term change in vegetation community structure and composition. The information generated will support land management decisions that concern the natural and cultural value of the coastal heathlands, increase our understanding of vegetation dynamics, and support appropriate conservation of coastal heathland landscape (Roman and Barrett 1999).

MONITORING QUESTIONS:
1. Is the extent of the floristic changes over the ten-year study period statistically and/or biologically significant?
2. Which canopy species shows the greatest incursion?

3. What are the effects of various correlates relating site to reproductive vigor of key plant species, site stability, geography, and history?

STATUS: In Development
A proposal describing the methods and procedure for developing a heathland monitoring protocol was submitted and approved in 2000. Vegetation data from permanent heathland plots established in 1988 (Carlson et al. 1992) and resurveyed in 1999, and environmental data collected in 2002 is currently being analyzed. A draft protocol is expected in early 2003, and the heathland monitoring protocol expected by mid 2003.

CITATIONS:

Carlson, L., M. Babione, P. Godfrey, and A. Fowler. 1992. *Final Report: Ecological Survey of the Heathlands in Cape Cod National Seashore*. National Park Service, North Atlantic Region, Office of Scientific Studies. NPS/NAROSS/NRTR-92/04.

Dunwiddie, P.W., R.E. Zaremba, and K.A. Harper. 1996. A classification of coastal heathlands and coastal sandplain grasslands in Massachusetts. *Rhodora* 98:117-145.

COASTAL FORESTS

PRINCIPAL INVESTIGATOR/COOPERATORS:
Stephen Smith, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:
Woodland and forest communities occupy the largest land-surface area and biovolume of any vegetation component within CACO. As such, forest structure and function may be important indicators of general ecological health across the CACO landscape. A number of natural and anthropogenic agents of change have been identified for this system (Roman et al. 1999). These include chronic and episodic weather factors (e.g., salt spray, wind), fire and fire suppression, disease, invasive species, succession, fragmentation by development, air pollution, acid deposition, ultraviolet radiation, and global warming. It is noteworthy that pitch pine (*Pinus rigida*), perhaps the most abundant tree species at CACO, has been identified as one of the most sensitive species to air pollutants, particularly SO_2 (Davis and Wilhour 1976). Thus, the need to conduct rigorous monitoring is critical for making accurate assessments of forest health and the underlying mechanisms of change.

This protocol is most closely linked with heathland and grassland monitoring protocols given that these communities are being subsumed by forests through succession. Monitoring forest resources also will provide valuable information on habitat conditions for a variety of birds, mammals, and herpetofauna.

MONITORING QUESTIONS:
1. How does forest structure, function, and landscape pattern vary temporally and spatially across the landscape?
2. Which physical, chemical, and biological factors have the greatest influence on spatial and temporal variability?
3. Are anthropogenic stresses altering the natural dynamics of forest ecosystems within CACO?
4. How should CACO forests be managed (e.g., prescribed fire) to preserve ecologically important attributes of the system?

STATUS: In Development
A general plan for the monitoring protocol was proposed in 1999 (Barrett, 1999) as a way to integrate the previous work of Patterson et al. (1983) and Chokkalingham (1993) with the newer, widely used methodology of Peet et al. (1998). The plan was then implemented during the 2001 field season. In 2002, a number of revisions were made to correct some procedural flaws and improve the quality and efficiency of fieldwork. In addition, a large amount of data was re-acquired to better facilitate comparisons with the pre-existing data.

Several new parameters representative of biogeochemical processes are currently being assessed to determine their value as bioindicators. In this regard, litterfall (Haapala et al., 1996, Lamppu and Huttunen 2001), litter quality (Manninen and Huttunen 1995, Wookey et al. 1991), sulfur isotope analysis (Alewell et al. 1999), litter decomposition, needle morphology and injury (Tichy 1996), root starch (Dunn et al. 1987, Dunn and Potter 1990), and mycorrhizae colonization (Reich et al. 1986) have emerged as potential candidates for testing in the 2003 field season. Finally, new sampling sites will be added to encompass several other forest types (e.g., Red Maple, Black Locust, Atlantic White cedar) not included in the existing network.

CITATIONS:

Alewell, C., M. Mitchell, G. Likens and R. Krouse. 1999. Sources of stream sulfate at the Hubbard Brook Experimental Forest: long-term analysis using stable isotopes. Biogeochemistry 44:281-299.

Barrett, N.E. 1999. Proposed sampling protocols to be tested for a vegetation survey and monitoring porgram at Cape Cod National Seashore. U.S. Department of the Interior, National Park Service, Cape Cod National Seashore, Wellfleet, MA.

Chokkalingham, U. 1993. Recent disturbance-mediated vegetation change at Cape Cod National Seashore, Massachusetts. Master's Thesis. Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA.

Davis, D.D. and R.G. Wilhour. 1976. Susceptibility of woody plants to sulfur dioxide and photochemical oxidants. Tech pub EPA-600/3/76/102. Corvallis Enviornmental Research Laboratory, Office of Resarch and Development. U.S. Environmental Protection Agency. Corvallis OR.

Dunn J.P. and D.A. Potter. 1990. Can tree susceptibility to borers be predicted from root starch measurements. Journal of Arboriculture. 16:236-239.

Dunn J.P., T.W. Kimmerer, and D.A. Potter. 1987. Winter starch reserves of white oak as a predictor of attack by the twolined chestnut borer, Agrilus bilineatus (Weber). Oecologia 74:352-355.

Haapala, H., Goltsova, N., Seppala, R., Huttunen, S., Kouki, J., Lampp, J., Popovichev, B. 1996. Ecological condition of forests around the eastern part of the Gulf of Finland. Environmental Pollution 91(2):253-265.

Lamppu, J. and S. Huttunen. 2001. Scots pine needle longevity and gradation of needle shedding along pollution gradients. Canadian Journal of Forest Research 31(2):261-267.

Manninen, S. and Huttunen, S. 1995. Scots pine needles as bioindicators of sulphur deposition. Canadian Journal of Forest Research 25(10):1559-1569.

Patterson, W. A., K.E. Saunders, L.J. Horton. 1983. Fire regimes of Cape Cod National Seashore. Report # OSS 83-1. U.S. Department of the Interior, National Park Service, North Atlantic Region, Office of Scientific Studies, Boston, MA.

Peet, R.K., T.R. Wentworth, and P.S. White. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63:262-274.

Reich, P.B., H.F. Stroo, A.W. Schoettle, and R.G. Amundson. 1986. Acid rain and ozone influence mycorrhizal infection in tree seedlings. Journal of the Air Pollution Control Association 36:724-726.

Tichy, J. 1996. Impact of atmospheric deposition on the status of planted Norway spruce stands: a comparative study between sites in southern Sweden and the northeastern Czech Republic. Environmental Pollution 93(3): 33-312.

Wookey, P., A. Ineson, and P. Oxford. 1991. Chemical changes in decomposing forest litter in response to atmospheric sulphur dioxide. The Journal of Soil Science 42(4):615-628.

REPTILES

PRINCIPAL INVESTIGATORS/COOPERATORS:
Robert Cook, Wildlife Ecologist, NPS-CACO; funding from NPS-CACO I&M

JUSTIFICATION:
Reptiles comprise a diverse group of vertebrates that occupy a broad range of habitats and ecological functions. As mid- to high- order predators they are important in energy flow, and some groups (e.g. aquatic turtles) often dominate vertebrate biomass (Congdon et al. 1986). By virtue of their trophic position, biomass, and vulnerability to many anthropogenic perturbations, reptiles can be important indicators of environmental quality (Gibbons and Stangel 1999). Reptile populations appear to be declining throughout most of the U.S. and globally, due to the combined impacts of habitat loss and degradation, invasive species, pollution, disease, unsustainable use, and global climate change (Gibbon et al. 2000).

CACO supports populations of 12 species of non-marine reptiles, occupying terrestrial, freshwater, and estuarine habitats. These include presently common and/or widespread species such as painted turtle (*Chrysemys picta*), snapping turtle (*Chelydra serpentina*), Northern ring-necked snake (*Diadophis punctatus edwardsii*) and black racer (*Coluber constrictor*) as well as the State Threatened Northern diamondback terrapin (*Malaclemmys t. terrapin*) , and two Special Concern species, spotted turtle (*Clemmys guttata*) and Eastern box turtle (*Terrapene c. carolina*). Whereas reptile communities composed of viable populations of the appropriate native species are indicative of intact native habitats and landscape processes, there are several agents of change operating at CACO that have the potential to affect the reptile community and component species at CACO. These include land use and development adjacent to the park, fire suppression, pollution, recreational use, and exploitation. Some of the mechanisms by which these agents can negatively affect reptile abundance include:

- alteration of aquatic habitats due to changes in water level (groundwater withdrawal), salinity (tidal alterations), and plant communities (invasive plants and groundwater withdrawal);
- declines in prey species abundance due to pesticide use or changes in aquatic habitats, particularly for food specialists such as the obligate toad-eating Eastern hognose snake;
- increased road kill as local population and visitation increases;
- increased predation of turtle nests by overabundant populations of native predators;
- loss of open nesting sites for turtles as fire suppression alters patch dynamics; and
- direct loss of animals to collection by visitors.

Since trends in reptile abundance are the product of many parameters, reptile monitoring will incorporate data from other protocols, particularly water quality, hydrology, pond vegetation, forest vegetation, vegetation mapping, and meso-mammals.

MONITORING QUESTIONS:

1. What are trends in population levels of selected reptile species, particularly painted turtle, spotted turtle, box turtle, and hognose snake?
2. How do trends in population levels relate to changes in habitats (e.g. water levels, water quality, vegetation) at or adjacent to monitoring sites.
3. What are trends in population age structure and how do they relate to trends in abundance?
4. How do trends in box turtle population levels in different sections of the park relate to habitat fragmentation and density of adjacent development?
5. To what extent can funnel trapping, coverboards, and incidental captures provide data useful for estimating abundance and describing population structure in park reptiles.

STATUS: In Development

In conjunction with parkwide reptile inventory 2000-2002, funnel traps (for aquatic turtles) and coverboards (for snakes) were tested for use in monitoring. Data will be used to determine their utility in generating population estimates to base long term monitoring on, as well as to determine best measures of abundance, age and sex structure. Based on frequency of captures, funnel traps appear to provide sufficent captures to generate numerical estimators of aquatic turtle populations whereas captures of snakes under coverboards do not.

Recommendations will likely call for continual monitoring of box turtles and eastern hognose snakes by marking incidentally captured individuals and periodic (every 3-5 years) monitoring of freshwater species (primarily spotted and painted turtles) to provide population estimates and evaluate population structure.

CITATIONS:

Congdon, J. D., J.L. Greene, and J.W. Gibbons. 1986. Biomass of freshwater turtles; A geographic comparison. Am. Midl. Nat. 115:165-173.

Gibbons, J. W. and Stangel, P.W. (coordinators). 1999. Conserving amphibians and reptiles in the new millenium. Proceedings of the partners in amphibian and reptile conservation (PARC) conference. 1999. Savannah River Ecology Laboratory Herp Outreach Publication#2. Aiken SC.

Gibbons, J.W., D.E. Scott, T.J. Ryan, K.A. Buhlmann, T.D. Tuberville, B.S. Metts, J.L Greene, T. Mills, Y. Leiden, S. Poppy, and C.T. Winne. 2000. The global decline of reptiles, déjà vu amphibians. BioScience 50(8):653-666.

LANDBIRDS - AVIAN POINT COUNTS

PRINCIPAL INVESTIGATORS/COOPERATORS:
Curtice Griffin and Mark Faherty, University of Massachusetts, Amherst; funding from NPS-CACO I&M

JUSTIFICATION:
The goal of this work is to provide the first systematic park-wide inventory of breeding landbirds and analysis of habitat associations, and to test the use of avian point counts for landbird monitoring at CACO.

Because of their high body temperature, rapid metabolism, and relatively high position on most food webs, landbirds may be excellent indicators of the effects of environmental change. In addition, their abundance and diversity in most habitats, diurnal nature, discrete seasonal reproduction, and intermediate longevity facilitate their monitoring.

CACO is an important breeding and migration stop for neotropical landbirds, and supports many state-listed and watch-listed rare species. Recent analyses of data from regional monitoring programs, such as Breeding Bird Surveys, suggest that populations of many landbirds, including forest, shrub, and grassland inhabiting species are in serious declines. CACO-specific work confirms this trend for grassland species (Kearny and Cook 2001). While declines are or may be occurring, the source or cause of the declines is often not known, and may be the result of factors operating during the breeding season (e.g. at CACO), during migration, or on wintering grounds.

At CACO, the occurrence, distribution, species composition, and abundance of landbirds is primarily the product of habitat factors and human factors such as disturbance by visitors and disturbance and predation by pets. These factors are themselves the result of landscape level changes that are occurring as a result of post-agrarian plant succession, increased residential development, and visitation. Some of the more specific ways in which these agents of change manifest themselves and potentially act as stresses affecting landbirds are:

- succession of grassland/heathland habitats to shrub and pine forest, succession of pine to oak forest, and maturation of oak forest;
- habitat changes due to alien plant domination;
- increased edge effects and cowbird parasitism
- increased frequency and intensity of human presence; and
- increased numbers of pets disturbing or preying upon landbirds.

In contrast to the MAPS project (see the following protocol summary), the avian point-count protocol will provide landbird status and trend information for landbirds across the park's coastal uplands.

Given the strong relationship of breeding landbirds to habitat variables, landbird monitoring will include data collection on habitat variables at sampling sites, and will also draw on vegetation monitoring and mapping data for interpretation of trends.

MONITORING QUESTIONS:

1. What species of landbirds are breeding at CACO, and what is their distribution and abundance?
2. How does the distribution and abundance of landbirds breeding at CACO relate to habitat types and habitat variables?
3. What are the temporal trends in the occurrence, distribution, and abundance of landbirds breeding at CACO?
4. How do temporal trends in the occurrence, distribution, and abundance of landbirds breeding at CACO relate to temporal trends in habitat variables?

STATUS: In Development

While the above questions constitute the biological questions of interest, an additional, methodological question is to determine the adequacy of Variable Circular Plot data collected at CACO for answering the biological questions. Field testing of the protocol (Griffin 2000) was conducted in 2001 and 2002, with a third season planned for 2003. Work in 2003 will replicate that of 2002, to compare results obtained from one v. two consecutive field seasons.

CITATIONS:

Griffin, C. R. 2000. Inventory and development of monitoring protocols for landbird communities at Cape Cod National Seashore. Univ.of Massachusetts at Amherst, Dept. of Natural Resources Conservation. 9pp.

Kearny, S.B. and Cook, R.P. 2001. Status of grassland and heathland birds at Cape Cod National Seashore. USDI, NPS, Boston Support Office, Technical Report NPS/BSO-RNR/NRTR/2002-3

LANDBIRDS - MONITORING AVIAN PRODUCTIVITY AND SURVIVORSHIP (MAPS)

PRINCIPAL INVESTIGATORS/COOPERATORS:
David DeSante, Institute for Bird Populations; funding from USGS-BRD and NPS-CACO I&M

JUSTIFICATION:
Because of their high body temperature, rapid metabolism, and relatively high position on most food webs, landbirds may be excellent indicators of the effects of environmental change. In addition, their abundance and diversity in most habitats, diurnal nature, discrete seasonal reproduction, and intermediate longevity facilitate their monitoring.

CACO is an important breeding and migration stop for neotropical landbirds, and supports many State listed and Watch-listed rare species. Recent analyses of data from regional monitoring programs, such as Breeding Bird Surveys, suggest that populations of many landbirds, including forest, shrub, and grassland inhabiting species are in serious declines. CACO-specific work confirms this trend for grassland species (Kearny and Cook 2001). While declines are or may be occurring, the source or cause of the declines is often not known, and may be the result of factors operating during the breeding season (e.g. at CACO), during migration, or on wintering grounds.

At CACO, the abundance, survival, productivity, and species composition of landbirds is primarily the product of habitat factors and human factors such as disturbance by visitors and disturbance and predation by pets. These factors are themselves the result of landscape level changes that are occurring as a result of post-agrarian plant succession, increased residential development, and visitation. Some of the more specific ways in which these agents of change manifest themselves and potentially act as stresses affecting landbirds are:

- succession of grassland/heathland habitats to shrub and pine forest, succession of pine to oak forest, and maturation of oak forest;
- habitat changes due to alien plant domination;
- increased edge effects and cowbird parasitism
- increased frequency and intensity of human presence; and

increased numbers of pets disturbing or preying upon landbirds.

In contrast to the avian point-count protocol, the MAPS project will provide more focused information on survival, productivity, and the effects of residential development and habitat fragmentation on landbird assemblages.

Given the strong relationship of breeding landbirds to habitat variables, landbird monitoring will include data collection on habitat variables at sampling sites, and will also draw on vegetation monitoring and mapping data for interpretation of trends.

MONITORING QUESTIONS:

1. What is the temporal variation (e.g. long-term trends) in productivity indices and adult survival rate estimates of landbirds within CACO and how are these trends affected by the composition and volume of vegetation types and park management practices?

2. Does the density or spatial distribution of houses and roads within and adjacent to CACO affect the species composition and productivity of landbirds?

3. How are changes in landscape heterogeneity affecting particular species of forest interior or early successional landbirds.

STATUS: Protocol - Completed; Monitoring - Operational (by IBP)

While the above questions constitute the biological questions of interest, an additional, methodological question is whether data collected at CACO in accordance with the MAPS protocol (DeSante 2001) will be adequate to answer them. A five year field test began in 1999 and will continue through the 2003 field season. A detailed analysis will be conducted, focussed on both the biological as well as methodological questions. Preliminary analysis, based on two years' data, found productivity:

- decreased from pine forest, to pine-oak, to oak forest;
- was higher at sites with dense understory; and
- was unaffected by adjacent housing density (DeSante et al. 2001).

CITATIONS:

DeSante, D. F. 2001. The Monitoring Avian Productivity and Survivorship (MAPS) program at Cape Cod National Seashore. Institute for Bird Population. A monitoring protocol for the long-term coastal monitoring program at Cape Cod National Seashore. The Institute for Bird Populations.

DeSante, D.F., N. Michel, and D.R. O'Grady. 2001. The 2000 annual report of the Monitoring Avian Productivity and Survivorship (MAPS) program in Cape Cod National Seashore. 38 pp.

Kearny, S.B. and Cook, R.P. 2001. Status of grassland and heathland birds at Cape Cod National Seashore. USDI, NPS, Boston Support Office, Technical Report NPS/BSO-RNR/NRTR/2002-3

SMALL MAMMALS

PRINCIPAL INVESTIGATOR/COOPERATORS:

Robert Cook, Wildlife Ecologist, and Kelly Boland, Wildlife BioTech, NPS-CACO

JUSTIFICATION:

Small mammals are a key component driving trophic dynamics of most wildlife communities. They consume plant material and invertebrates and serve as prey items for a number of species of snakes, raptors and small and mid-sized carnivores. Through these relationships, small mammals may directly influence population levels of insect pests and disease vectors such as gypsy moths and deer ticks, as well as regionally rare birds of prey, and have a cascading effect up and down the "food chain". In addition to their direct influence on other wildlife, small mammals influence vegetation composition. Through seedling predation, small mammal abundance and composition affects the plant community structure (Ostfeld 2002).

At CACO, foxes and other carnivores prey upon nests of colonial waterbirds and shorebirds such as the federally threatened piping plover. Since small mammals serve as a food source for these predators, variation in their abundance may affect predation pressure on these birds (Bennett 1998). Small mammal abundance and community structure at CACO is influenced by agents of change such as fire suppression, exotic species introduction, and habitat succession. Some of the mechanisms by which these agents of change affect small mammal abundance include loss of herbaceous dominated habitat from suppression of fire, human caused predator increases such as skunks and red foxes, and declines in foraging material from replacement with exotic plants. In turn however, small mammals also act as agents of change, influencing abundance of predators and pest species, as well as the species composition of plant communities.

Since trends in mammal abundance are mainly the product of habitat structure and succession, small mammal monitoring will incorporate data from vegetation monitoring in its analysis.

MONITORING QUESTIONS:

1. What is the distribution, abundance, and species composition of small mammal communities in oak and pine forest, wetland, grassland and heathland habitats at CACO?

2. What are the temporal trends in the occurrence, distribution, abundance and composition of small mammal communities at CACO?

3. How do temporal trends in the occurrence, distribution, abundance, and species composition of small mammals at CACO relate to temporal trends in environmental variables such as plant community structure and composition?

4. How do spatial and temporal trends in small mammal communities influence the abundance of mammalian predators, such as red fox and coyote?

STATUS: Protocol - Completed; Monitoring - Field Testing and Analysis
Field testing of the protocol (Bennett 1998) was conducted in 2000 and 2001. Data are currently being analyzed along two lines. The first will be methodological, critiquing methods for estimating survival (Program JOLLY) and abundance (CAPTURE, Lincoln-Peterson) and determining the most feasible or optimal based on CACO-data. This will form the basis for protocol recommendations. The second component will be an inventory report, focused on small mammal ecology, habitat associations, and community structure.

Partial analysis suggests that data are inadequate to reliably estimate survival using JOLLY or abundance using CAPTURE. A recommendation will likely be to use Lincoln-Peterson as abundance estimator, and repeat monitoring every 3-5 years.

CITATIONS:
Bennett, A., 1998. Protocol for Sampling Small Mammals at Cape Cod National Seashore. Cape Cod National Seashore, Wellfleet MA. 32pp.

Ostfeld, R.S., 2002. Little loggers make a big difference. Natural History 111: 64-71.

MESO-MAMMALS/CARNIVORES

PRINCIPAL INVESTIGATOR/COOPERATORS:
Allan O'Connell, USGS, Patuxent Wildlife Research Center; funding from NPS-NER and USGS-BRD

JUSTIFICATION:
Medium-sized mammals are an important component of CACO's fauna. Consisting of several species that differ markedly in their abundance and degree of conspicuousness, the majority of meso-mammals are carnivorous, feeding primarily on small mammal and invertebrate prey. Many have been, or potentially may be involved in issues relating to predation or human conflict. Examples include skunks and raccoons as subsidized predators, red fox (a non-native species) preying upon terns and the Federally-threatened piping plover, and coyotes as a species that creates a degree of controversy by its mere presence.

Agents of change related to increased human presence in and adjacent to CACO influence abundance of meso-mammals. Residential development creates edges and anthropogenic food sources (e.g. gardens, garbage, pet foods), and increased traffic can result in road kill. These, in turn, may result in conflicts with humans (e.g. deer, coyote), or may act as stresses on populations of native species, such as turtles, terns, and piping plovers. Thus while tracking the distribution and abundance of this group is important, because of the range in size and degree of conspicuousness, they are difficult to monitor and there is virtually no information on utility of monitoring techniques in coastal environments.

Given that most meso-mammals are predators, analysis of monitoring data would incorporate data from small mammal monitoring, piping plover/colonial waterbird monitoring, and reptile monitoring, as well as provide data to be used in the analysis of these protocols' data.

MONITORING QUESTIONS:
1. What are the population levels of the various species of meso-mammals at CACO?
2. How do trends in population levels of meso-mammals at CACO relate to trends in small mammals, and predation levels on species of interest, e.g. piping plover?

Specific methodological questions being tested include:
1. Which techniques are most useful for documenting medium-sized mammals in coastal environments?
2. Which technique can "capture" the greatest number of species with the least amount of effort?
3. How many techniques are needed to document the entire mammalian community?

4. How much effort is needed to capture the various target species?
5. Which technique and level of sampling effort is best at providing data capable of tracking trends in meso-mammal abundance?

STATUS: In Development

Field testing of methods to detect the presence of meso-mammals was conducted from fall 2000 to spring 2002. Methods tested were active and passive remote cameras, tracking plates, cubby boxes, and hair snagging devices. For all methods combined, six of eight potentially occurring target species were recorded. However, active remote cameras (6 species detected), cubby boxes (5 species), and hair traps (5 species) were found to work best. These devices are now being used to sample in five different habitats to test their utility in producing abundance estimates or indices. Sampling is being conducted from June through December 2002.

METEOROLOGIC AND ATMOSPHERIC MONITORING

PRINCIPAL INVESTIGATOR/COOPERATORS:
Krista Lee, NPS-CACO; funding from NPS-CACO NRM and I&M, and NPS-NER

JUSTIFICATION:
Meteorological and atmospheric processes are an important influence in many of Cape Cod's ecosystems. For example, precipitation is the most significant source of the lower Cape's surface and ground-water systems, winds and storm surges reshape dunes and shorelines, and marine aerosols influence the distribution of plant assemblages across the Cape. Understanding and detecting trends in these processes is critical to interpreting changes seen in other ecosystem parameters. The Cape also receives air-borne pollutants from the high density population and industrial centers of the northeastern region of the United States. Pollutants with the potential to impact the Cape's resources include ozone, mercury, nitrogen oxides, sulfur dioxide, particulates, and volatile organic compounds.

This protocol, particularly the meteorological component, is relevant to nearly all the other monitoring components of this program. Those that are the most closely tied to the atmospheric component include estuarine nutrient enrichment, kettle pond water quality, freshwater aquatic invertebrates, freshwater fish, pond-breeding amphibians, lichens, and potentially all vegetation monitoring protocols.

MONITORING QUESTIONS:
1. What are the predominant trends in meteorological parameters such as wind speed and direction, air temperature, precipitation amount and duration, relative humidity, total solar radiation, net radiation, and photosynthetically active radiation?
2. What is the contribution of atmospheric wet chemistry inputs (such as acids, base cations, mercury, inorganic nitrogen) to aquatic and terrestrial systems?
3. What are the predominant trends in air quality parameters such as ozone, nitrogen oxides, sulfur oxides, particulates, and volatile organic carbons?

STATUS: Protocol - In Development; Monitoring - Operational
The park has been collecting a variety of meteorological and atmospheric data for varying lengths of time, depending on the type of monitoring. Ongoing monitoring includes participation in the National Atmospheric Deposition Program, the Interagency Monitoring of Protected Visual Environments Program, ozone and other air quality parameter monitoring through the State's air quality program, and a variety of weather stations operated by the park or by the National Oceanographic and Atmospheric Administration. In addition, the Natural Resources Management Division received regional funding in 2002 to initiate monitoring for atmospheric deposition of mercury.

In 2001 a document was compiled that describes the relevant meteorological and atmospheric data being collected by the park (USGS 2001). A program-specific protocol is still needed to document data collection procedures, specify what data is to be obtained by other sources, and describe the data management procedures that will integrate this information.

CITATIONS:

USGS, URI, CACO. 2001. Summary of meteorological and atmospheric monitoring protocols for Cape Cod National Seashore. Technical Report, USGS Patuxent Wildlife Research Center, University of Rhode Island, Narragansett. 25pp..

CONTAMINANTS

PRINCIPAL INVESTIGATOR/COOPERATORS:
James Quinn, Robert Cairns, Paul Hartman, and John King, Graduate School of Oceanography, University of Rhode Island; funding from USGS-BRD
Mark Robson, Rutgers University; funding from NPS-NC&B Network

JUSTIFICATION:
As discussed in the summaries of the ground-water quality, pond water quality, estuarine nutrient enrichment, and atmospheric monitoring protocols, all of CACO's ecosystems are vulnerable to impacts from pollutants. Specific contaminants that have been identified as known or potential threats to the park's biological resources include mercury, ozone, and anthropogenically elevated nutrients. The 1999 Conceptual Framework also identified accumulation of petroleum hydrocarbons in estuarine sediments and benthic fauna as a potential concern. Past and planned studies and monitoring efforts are helping us to better understand the sources, pathways, and effects of these and other known stressors. In addition to these focused efforts, a comprehensive assessment is needed to identify other known or potential contaminants, assess the risk they pose to CACO's ecosystems, and identify monitoring priorities.

The comprehensive assessment and subsequent monitoring will be tied to the ground-water quality, pond water quality, estuarine nutrient enrichment, and atmospheric monitoring protocols.

MONITORING QUESTIONS:
1. What is the current status of contaminants within the park?
2. What are the ecological risks associated with each xenobiotic identified?
3. Are conditions changing over time? Are contaminants persisting from past releases? Are there releases that are ongoing?
4. If an upgradient source is identified, how do we determine if the source is a threat to park resources?

STATUS: In Development
In response to the recommendation in the 1999 Conceptual Framework, a study was conducted to assess hydrocarbons in estuarine sediments and benthic fauna. This study found that in all but one area, estuarine surface sediments had hydrocarbon contaminant concentrations below the established effects range median (ERM). The one exception was from Hatches Harbor and exceeded the ERM guidelines for two classes of hydrocarbons (Quinn, et al 2001). The Environmental Contaminants Baseline Inventory and Monitoring project was initiated by the NC&B Network with technical leadership from CACO. An assessment and monitoring recommendations will be developed for each park in the network with the initial effort focusing on CACO.

CITATIONS:

Cooper, K. Undated. Environmental Contaminants Baseline Inventory and Monitoring for National Parks (Proposal). 6pp. CACO files.

Quinn, J. G., R.W. Cairns, P.C. Hartmann, and J.W. King. 2001. Final Report: The Study of Organic Contaminants in Coastal Ponds and Marshes in the Cape Cod National Seashore. CACO files. 15pp with appendices.

HYDROLOGY

PRINCIPAL INVESTIGATOR/COOPERATORS:
Tim McCobb and Peter Weiskel, USGS-WRD; funding from USGS-BRD

JUSTIFICATION:
Water resources of outer Cape Cod are diverse and of high quality; they include a sole-source aquifer, kettle ponds, permanent and seasonally flooded freshwater wetlands, freshwater streams and estuarine wetlands. However, rapid urbanization comprises a serious threat to these resources requiring comprehensive protection, management and monitoring actions (Godfrey et al. 1999). First, increased pumping for public water supply can alter the dynamic balance between fresh and salt water at depth in the aquifer, leading to shifts in the location of the salt/fresh interface and causing salt-water intrusion into pumping wells (Barlow 2000). Second, urbanization also reduces aquifer recharge rates because impervious surfaces allow runoff to directly enter coastal waters, circumventing the groundwater system. Third, urbanization can lead to exports or imports of water between adjacent flow cells, affecting water balance in both and in dependent ponds, streams, freshwater wetlands and estuaries.

In addition climatic change and sea-level rise may radically alter Park ecosystems via the hydrologic system. Sea-level rise along the Massachusetts coast, averaging 2.6 mm yr^{-1} during the 20th century is predicted to increase to 3.5-6.0 mm yr^{-1} by the year 2100 due to global warming and glacio-isostatic adjustment (Donnelly and Bertness 2001). The response of the Cape hydrologic system to accelerated sea-level rise will likely be an increased tendency for salt water to intrude both the underlying aquifer and tidal streams. In addition, surface runoff may increase, with a concurrent decrease in groundwater discharge. These hydrologic changes have potential effects on sediment salinity and nutrient fluxes in the coastal zone (Nuttle and Portnoy 1992).

Climate change can also affect stream discharge. Although long-term stream flow records are lacking for Cape Cod, well hydrographs show the effects of decade-scale climate change on the hydrologic system. It can be inferred from these data that streams and wetlands on Cape Cod are similarly affected by declines in ground-water levels because of the close connection between ground water, streams and wetland systems on the Cape (LeBlanc et al. 1986, Sobczak and Cambareri 1995, Masterson et al. 1998).

This protocol is closely linked to kettle pond water quality, freshwater invertebrate, amphibian, dune slack wetlands, ground-water quality, contaminants, vernal wetland vegetation, kettle pond vegetation, and estuarine nutrient enrichment protocols.

MONITORING QUESTIONS:

1. Do existing pumping patterns on or near CACO cause salt-water intrusion? Could proposed pumping cause intrusion?
2. Do land uses in the urbanizing areas of the outer Cape lead to increased, decreased or unchanged recharge rates compared to the land uses that they replace?
3. What are sustainable, long-term rates of ground water export from each flow cell that will not cause substantial change in ground-water level?
4. What are the localized drawdown effects of groundwater pumping upon ponds and vernal pools?
5. Will the salt-water/fresh-water interface at the base of the ground-water flow system respond immediately to accelerated rates of sea-level rise and will this threaten public supply wells?
6. How much further inland will tidal influence and saline water penetrate CACO's coastal streams and associated ecosystems in the coming decades?
7. How will the water balance of CACO's landscape be affected by sea-level rise?
8. What are the long-term trends and periodicities in ground water levels in CACO and how do they relate to climatic records?
9. How well correlated are ground water, stream flow and climatic data on Cape Cod and what can be inferred about the likely ecological effects of extremely high or low (drought) water levels in the future?
10. What would be the combined effectes of projected sea-level rise and drought-induced recharge decline on public water supplies?

STATUS: Protocol - Completed; Monitoring - To Be Initiated in 2003

A final draft protocol was completed in July of 2002 and the final version will be printed during the fall. We have been collecting a variety of hydrologic data for several years; in recent years much of this data collection has been consistent with portions of the protocol. We expect to begin formal implementation of the protocol in 2003.

CITATIONS:

Barlow, P.M. 2000. Atlantic Coastal Zone: U.S. Geological Survey Fact Sheet 085-00. 4p.

Donnelly, J.P. and M. D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. Proc. Nat. Acad. Sci. 98:14218-14223.

Godfrey, PJ, K, Galluzzo, N. Price and JW Portnoy. 1999. Water Resources Management Plan, Cape Cod National Seashore.

LeBlanc, D.R., J.H. Guswa, M.H. Frimpter and C.J. Londquist. 1986. Groundwater resources of Cape Cod, Massachusetts: US Geological Survey Hydrologic Investigations Atlas HA-692.

Masterson, J.P., D.A. Walter and D.R. LeBlanc. 1998. Delineation of contributing areas to selected public-supply wells, western Cape Cod, Massachusetts: US Geological Survey Water-Resources Investigation Report 98-4237. 42 p.

Nuttle, W.K. and J.W. Portnoy. 1992. Effects of rising sea level on runoff and groundwater discharge to coastal ecosystems. Estuarine, Coastal and Shelf Science 34:203-212.

Sobczak, R. and T.C. Cambareri. 1995. Lower Cape Management Task Force Interim Report. Cape Cod Commission.

GROUND-WATER QUALITY

PRINCIPAL INVESTIGATOR/COOPERATORS:
John Colman and Peter Weiskel, USGS-WRD; funding from NPS-CACO I&M

JUSTIFICATION:
Ground water is a critical component of sensitive habitats such as kettle ponds, vernal ponds, and estuaries. The lower Cape is also completely dependent on its aquifer for drinking water. The quality and quantity of ground water can be affected by global- and regional-scale influences such as drought, sea level rise, and atmospheric deposition of mercury, sulfate, and nitrate. The lower Cape's ground water is also affected by local factors associated with increasing urbanization such as private and municipal water withdrawals, septic systems, landfills, and run-off from impervious surfaces. Due to the importance of ground water to the ecological health of the lower Cape and its vulnerability to a variety of agents of change, the 1999 Conceptual Framework proposed development of a baseline ground-water hydrology and quality protocol.

A protocol for monitoring surface- and ground-water hydrology has recently been completed. The objective of this protocol is to augment the long-term hydrologic monitoring with long-term information regarding ground-water quality. Air quality and meteorological monitoring results will help us understand how atmospheric deposition affects ground-water quality. Similarly, contaminants monitoring will shed more light on local sources of ground-water degradation. The data produced by this protocol will be important for interpreting the results of pond water quality and estuarine nutrient enrichment monitoring. We expect that a more complete understanding of changes in water quantity and quality will help us better understand changes in the plant, invertebrate, and vertebrate communities associated with CACO's aquatic and wetland habitats.

MONITORING QUESTIONS:
1. What are the temporal trends in background constituent concentrations (nutrients, major ions, alkalinity, pH, dissolved oxygen, dissolved organic carbon) in ground water underlying undeveloped recharge areas of the park?
2. What is the relationship between trends in these background constituents, soil processes, and precipitation chemistry?
3. What are the spatial and temporal trends in ground-water nutrient and toxic contaminant concentrations upgradient of sensitive aquatic and wetland habitats?
4. What are the temporal trends in known or suspected ground-water contaminant plumes located in or hydraulically upgradient of the park?

STATUS: In Development
A proposal was prepared in July of 2002, and the funds were obligated for this project near the close of FY 2002. This project will benefit from previous studies, including the hydrology monitoring protocol, conducted at CACO by the Hydrologic Investigations Section of USGS.

CITATIONS:

Weiskel, P.K. and J. Colman. 2002. Development of Protocols for Long-Term Monitoring of Ground-Water Quality, Cape Cod National Seashore, Massachusetts. CACO files. 5pp.

VISITOR USE AND RESOURCE IMPACT

PRINICIPAL INVESTIGATORS/COOPERATORS:
Jeffrey Marion, USGS Patuxent Wildlife Research Center, and Kerri Cahill, Doctoral Student, Virginia Tech; funding from USGS-BRD

JUSTIFICATION:
The majority of CACO visitors confine their activities to formal trails, park facilities, and those ocean and pond beaches with developed infrastructure (bathrooms, parking lots, etc). However, the pursuit of solitude, wildlife viewing, hiking, and other activities that bring visitors to less developed areas of the park are also very popular. Depending on the type and intensity of activity and the fragility of the habitats affected, dispersed recreational activities can have adverse impacts to ecosystem elements and processes. The 1999 Conceptual Framework identifies linkages among a variety of recreation-related agents of change, stresses, and possible system responses in all ecosystem types. The objective of this protocol is to monitor recreational activities with the highest potential to impact sensitive natural resources and document actual ecological effects. Likely areas of focus include proliferation of social trails in vegetated dunes, vegetation damage and erosion around kettle ponds, and disturbance to migrating shorebirds.

MONITORING QUESTIONS:
1. How are the amount, type, and temporal and spatial distribution of visitor uses changing over time?
2. What types of recreation-related resource degradation are occurring and how extensive are the impacts?
3. What is the impact of visitor activities on park wildlife populations?

STATUS: In Development
A proposal describing the approach to protocol development was prepared in 2000 (Marion and Cahill 2000). Field work was initiated in the summer of 2001.

CITATIONS:
Marion, J. and K. Cahill. 2000. Design and Testing of a Sampling Protocol for Monitoring Visitor Use and Resource Impact. CACO Files. 11pp.

INTERDISCIPLINARY STUDY AREAS

PRINCIPAL INVESTIGATOR/COOPERATORS:
John Portnoy, Steve Smith, Evan Gwilliam, Robert Cook, Krista Lee, Mark Adams, Kelly Boland, and Carrie Phillips, NPS-CACO

JUSTIFICATION:
The I&M program is to be driven by management issues[2] and, aside from attempts at basic biological inventory, is not intended to monitor everything everywhere in the park; rather the monitoring effort is intended to "focus on human constraints to the coastal ecosystem, but also account for natural processes and associated ecosystem responses to better understand natural variability and functions of ecosystems" (Roman and Barrett 1999). Thus, at the outset emphasis is placed on a monitoring strategy that aims at both documenting change (e.g. in climate, surface water quality, plant and animal distributions and abundance) and understanding the causes of change. Because we are dealing with whole ecosystems, an interdisciplinary research perspective is the most effective way to understand why things change.

Obviously, monitoring results and experiments from a variety of disciplines are most legitimately and meaningfully integrated into an understanding of the potential causes of change by co-locating observations and experiments. Thus, there is a need to co-locate the developing protocols and associated ecological research in study areas that we carefully select to represent the outer Cape landscape. In many cases study sites for protocol testing and development have already been selected to coincide with work in other disciplines. For example, the Park and cooperators are conducting (or plan to conduct) interdisciplinary monitoring in most major park estuaries; we need to expand this strategy into the park's interior encompassing "watersheds" or chunks of real estate that are both representative and large enough to assess and explain change in the biota that the park is mandated to preserve.

We therefore propose to establish interdisciplinary study areas for process-oriented study. This approach follows the model established in 1980 by the National Science Foundation with the initiation of the Long-Term Ecological Research (LTER) Program. Importantly, each study area is not a sampling unit. Experts in each discipline choose sampling sites within the study area to represent their variables of interest over the entire study area. Variables will be reviewed and chosen by the interdisciplinary team working and thinking together about postulated links between climate, atmospheric deposition, soils, microbes, plants, and animals. These links will be formalized as research questions or hypotheses and are based on relevant literature and unpublished local experience. In

[2] Groundwater quantity and quality, recreational impacts, human altered landscapes, species and habitat restoration, consumptive resource uses, air quality and pollution, sea-level rise.

some cases where specific environmental variables affect specific organisms of interest at small spatial scales, multiple team members, or perhaps the entire team, will need to contribute to the selection of specific sampling sites and variables, for example for the assessment of relationships among plant cover, litter depth and *Plethodon* salamander density.

MONITORING QUESTIONS:
Under development.

STATUS:
Staff have met to discuss the establishment of interdisciplinary study areas that are:

- physiographically distinct and recognizable by both natural resource professionals and others;
- represent typical CACO landscape features, biota and anthropogenic alterations or threats; and
- already have received moderate to extensive ecological study.

These study areas are physiographic park units where most or potentially all of the various protocols engaged in discipline-specific monitoring intersect. To date, identified ISAs include the Eastham vernal pond complex and associated upland, Nauset Marsh watershed, Wellfleet/Truro kettle ponds watershed and a representative portion the Province Lands dunes landscape.

CITATIONS:
Roman, C.T. and N. E. Barrett. 1999. The Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore. 59 p.